THE ANTECEDENTS and EVOLUTION of ABDOMINAL SURGERY for TRAUMA in WORLD WAR ONE

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World War One was the first of its kind to be fought on industrial battlefields, manifesting the employment of the newest forms of technologically-driven killing—from the land, air, and below the seas. High explosives with shrapnel-scattering bombs and grenades, and high velocity bullets from rifles and machine guns yielded a new class of horrific wounding, often multiple and random rather than targeted. Yet, those very advances in science and technology that developed the weaponry of the First World War also enabled novel medical and surgical wound management strategies, employing life-saving interventions unimagined only decades earlier. The First World War was unique among all wars, before and after, in the degree to which it exploited the fruits of contemporary scientific and technological advances for killing as well as for healing.

Since at least the time of the Romans and their *valetudinaria* (military hospitals), military medicine and surgery often kept abreast with, if not outpaced, medical developments in the civilian sector. The very opposite proved true concerning the evolution of abdominal surgery in the latter half of the 19th century. Major advances in abdominal surgery that developed in the civilian sector were not readily espoused by the military at the commencement of WWI. The circumstances leading to this lag of military surgical and medical innovation can be explained on the basis of the prevailing faulty medical theories, specious assumptions, prior experiences in military field hospitals, and conservatism among the military and medical establishments. Once the enormity of the human devastation caused during the opening months of the conflict was appreciated, progress was rapid and irreversible. A small number of free-thinking physicians in

the military willing to challenge current orthodoxy led to the evolution of methods for dealing with penetrating abdominal injuries. The lessons learned in the Great War led to advances which have determined medical and surgical care to this day not only in among the military, but have diffused into the civilian sector as well.

There are two watershed periods in the history of surgery in general, and abdominal surgery specifically, which are demarcated by events occurring within a span of twenty years of each other: the introduction of general anesthesia, and the introduction of antisepsis. The modern period of medicine commences from these two seminal break points. Medicine, general surgery, and the various surgical subspecialties as we know them could not have evolved without the development of general anesthesia beginning in 1846, and antiseptic technique first described in 1867. Both events were the culmination of scientific advances beginning with the Age of Enlightenment and the nascent Scientific Revolution, and brought to fruition in the 19th century. The American Civil War took place directly at the interface of these two eras in surgery, benefiting from the first, and concluding just short of the second.

Penetrating abdominal trauma resulting from accident and conflict has been manifest since the earliest times. Historically, treatment was limited to the removal of penetrating objects, hemostasis, reduction of prolapsed organs, analgesia, and closure of open wounds. Physical treatment was in tandem with herbal remedies, rituals, and incantations such as described in Homer's *Iliad.* In Homer's epic, abdominal wounds were produced almost exclusively by the thrusting spear and sword, all twenty-one penetrating wounds being lethal. Though the *Iliad* is fiction, it is the only account from antiquity of the type and incidence of wounding and death to be anticipated on a Late Bronze Age battlefield. In the *Iliad*, the incidence of penetrating abdominal injuries was 14.5% of 151 detailed wound descriptors,[1] a figure that remained

remarkably consistent through all subsequent conflicts until the gradual overshadowing of hand-to-hand combat and its casualties by the implementation of gunpowder and firearms.

Galen, the Greek physician-surgeon to Roman gladiators and emperors Marcus Aurelius and Commodus, was the first to write that surgery rather than medicine was the treatment of choice for wounds, including those of the abdomen.[2] Both he and Celsus described methods of reducing prolapsed bowel from a wound, and of suturing the abdomen closed.[3] [4] With the collapse of the Roman Empire, few advances in medicine and surgery were made, save for the Arabs. Albacusis (936-1013) wrote in his *kitab Al Tasrif* the first true description of abdominal surgery, including the anastomosis of disrupted intestine using fine sutures of animal gut.[5] By the European Late Middle Ages, a number of limited surgeries such as cutting for bladder stones, couching for cataracts, and the repair of groin hernias became widely practiced by itinerant barber-surgeons, reiterating forgotten Greek and Roman surgery. The rediscovery of ancient Greek and Roman medical texts, partly due to the Crusades and the influx of Islamic documents, formed an essential part of the Renaissance in Europe.

The introduction of gunpowder weaponry into the Middle East and Europe in the 14th century, with its "fierie engines" and attendant grievous injuries,[6] gave rise to a new specialty among the barber-surgeons, the *Kreigchirurgen* or "war surgeon" expert in the care of battle wounds. Regardless, the treatment of penetrating abdominal wounds, though made more critical by firearms, remained essentially unchanged from antiquity. Contemporary medical treatises largely eschewed surgical intervention for such wounds, apart from local wound management. Ambroise Páre (1510-90), a French barber-surgeon, war surgeon, and a father of modern military surgery, made major contributions to trauma surgery through reason and experimentation.[7] Apart from an anecdotal case of a sword wound to the abdomen treated successfully with medications

and judicious wound care, Páre was unable to make any contributions to the management of penetrating abdominal trauma, given the science and technology limitations of the time.

There were scattered anecdotal reports of successful treatment of abdominal injuries, virtually always the result of edged weapons rather than firearms, and limited to the repair and replacement inside the abdomen of prolapsed intestines and omentum. One such case was in 1676, involving a in butcher in Somerset, England, who attempted suicide by slicing open his abdomen. An anonymous surgeon replaced the prolapsed intestine, and removed the spleen and part of the omentum. The patient survived.[8] Other reports over the following century described colostomies (a surgical opening of the large bowel brought to the surface of the skin) done for obstruction of the bowels. In 1723, William Cheselden removed two feet of necrotic small bowel trapped within an umbilical hernia of a woman. She survived the operation, the ends of the bowel forming a permanent fecal fistula to the skin surface.[9] No accounts, however, are to be found of willful opening of the abdomen (laparotomy) to explore the abdominal cavity for penetrating trauma, particularly from gunshot wounds (GSWs).

The outcome of penetrating, intrabdominal trauma was well known, whether incurred by edged weapons or firearms. The prognosis was considered uniformly hopeless particularly with GSWs, with few cases of spontaneous recovery observed. The majority of those trauma cases usually resulted in rapid physiological "collapse" and demise from a syndrome LeDran in 1731 came to call "shock".[10a] If the initial wounding did not result in death, a progressive and often fatal inflammation of the abdominal cavity ensued over the next several days. In 1776, prominent Edinburgh physician William Cullen, who had been a ship's surgeon, described this abdominal inflammation and coined the term *peritonitis.*[11] The concept of infectious microorganisms

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a[7]The term "shock" was a mistranslation by British surgeon Clarke from the original term "choc" introduced by French surgeon LeDran in 1703, who used the term not for the syndrome produced, but for the violent impact of a ball against human flesh.

causing peritonitis and sepsis from perforated bowel and their contents entering the abdominal cavity was unknown.

A contemporary of Cullen, the famed Scottish scientist-surgeon John Hunter, served briefly as an army surgeon in 1760, and was staff surgeon on the expedition to the French island of Belle Île in 1761 during the Seven Years War. In 1794, he wrote his seminal work, *A Treatise on the Blood, Inflammation, and Gun-Shot Wounds*, based on his experiences in that conflict. His conclusion was that there was no place for surgery in gunshot wounds to the abdomen, advocating only "tepid baths" for those injured, in the forlorn hope of their natural recovery.[12]

The first true, elective—versus emergent—intraabdominal operation took place in 1809 in rural Kentucky. Ephraim McDowell, an Edinburgh-trained surgeon, removed a large ovarian tumor from a rural woman without benefit of anesthesia or antiseptic technique.[13] The woman survived and lived for another three decades, riding the sixty miles on horseback back to her farm twenty-five days after her surgery.[14] McDowell's success of surgically opening the abdomen for an elective operation was reported widely, but was not practical for most abdominal diseases, let alone penetrating trauma. A laparotomy for diagnosis and treatment of an intraabdominal disease process wasn't feasible until the advent of general anesthesia and antiseptic techniques.

Anesthetic chemicals were discovered well before they were used medically. The anesthetic volatile agents nitrous oxide ("laughing gas") and diethyl ether had been synthesized before McDowell's time by Joseph Priestley in 1772, and the German physician-botanist Valerius Cordus as early as 1540, respectively; chloroform was not synthesized until the 1830s. The effects of these agents on mood and consciousness, and their ablation of pain perception were known, though initially used as parlor entertainment and in dentistry rather than attempted for major surgery. The first demonstration of general (inhalation) anesthesia for major surgery,

using ether vapor, was conducted in Boston in October 1846 by the dentist John Morton at Massachusetts General Hospital.[15] [16] Within a year, ether for major operations was being employed routinely in England and the rest of Europe.[17] Ether anesthesia was first used by military surgeons in the Mexican-American War.[18] Chloroform was widely employed in the Crimean War by the English,[19] and ether introduced to the Russian Army field hospitals in that war by their eminent military surgeon, Nikolai Pirigoff.[20]

Notwithstanding, no formalized efforts at operating for abdominal trauma were seriously entertained, and the few attempts at surgical intervention in war yielded dismal results. The challenges of dealing with penetrating abdominal wounds remained, and was understandably most acute among the military surgeons. The surgical literature of the time reflects this, documenting many animal experiments on the repair of injured intestine conducted by surgeon-scholars in England and Europe, particularly the resection of intestine and techniques of anastomosis (surgical rejoining of the two ends of bowel). The techniques of abdominal surgery remained largely experimental, confined to the laboratories, and essentially unknown to most surgeons, let alone physicians.

By the American Civil War, both gunshot wounds to the head and the abdomen were treated "expectantly," pragmatically meaning that it was expected they would die. Morphine and opium with fluids administered by mouth were the only anodyne given. In a famous Alexander Gardner photograph taken three days after the Battle of Sharpsburg (Antietam), MD, in September 1862, the Confederate dead repose along the field of recent conflict. Their clothes are ruffled, allegedly a result of the wounded searching to determine if they had sustained a gut shot, with the knowledge that such an injury was virtually always fatal.

The dictums of John Hunter regarding abdominal trauma were reinforced by poor surgical outcomes during the American Civil War on through the Franco-Prussian War, the Balkan Wars of Independence, the French Moroccan War, the Spanish-American War, and Second Boer War. The premise of expectant management, a "wait and see" approach, became the ubiquitous orthodoxy for the management of penetrating abdominal wounds.[21] [22] Surgical intervention was not considered a viable treatment for trauma, even though abdominal surgery for disease became established in the waning decades of the 19th century in civilian hospitals. As an example, the great German military surgeon, Friedrich von Esmarch, wrote a textbook on war surgery based on his experience in the Franco-Prussian War (1870-71), but scant mention was made concerning abdominal wounds. Methods of cleansing GSWs and the repair of injured prolapsed intestine were described by him without oration of a hint of exploration of the abdominal cavity for penetrating wounds, despite the availability of general anesthesia.[23] Safe and successful abdominal surgery became possible only after the related developments of cell and germ theory which led to antiseptic principles.[b]

By 1839, cells were shown to be the basic unit of life, from unicellular bacteria to the complex cellular systems of all animals, inclusive of humans.[24] Unequivocal proof of specific bacteria as the cause of most infectious diseases was subsequently provided by Robert Koch, Louis Pasteur, and others, with effective vaccines soon developed for a number of the most virulent infections. Germ theory and proof resulted in the development of antiseptic techniques for surgery, initially advocated by Ignaz Semmelweis, and implemented by Sir Joseph Lister as first described in his 1867 paper on an antiseptic method in surgery.[25] Antiseptic technique

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b[7]Agostino Bassi, 1813; Schultze, 1837; Schleiden and Schwann, 1838-39; Cagniard-Latour, 1838; Ignaz Semmelweiss, 1847; John Snow, 1855; and Louis Pasteur, 1860-63, all were major contributors to cell theory.

allowed not only the feasibility and development of abdominal surgery, but surgery of the chest and brain.

Before that time, open wounds and surgical incisions, including amputations, suffered high rates of various hospital infections. In the current era, it is difficult to imagine the all too frequent infectious complications of surgery and wounding prior to antiseptic methodology. Consider the recollections of Sir Hector Cameron, house surgeon to Lister, preceding the introduction of sterile technique: "Every wound discharged pus freely, and putrefactive changes occurred in the discharges of all, producing in the atmosphere of every surgical ward, no matter how well ventilated, a fetid sickening odour, which tried the student on his first introduction to surgical work just as much as the unaccustomed sights of the operating theatre."[26] The primary infections all too common in hospitals of that era were erysipelas (streptococcal infection), pyemia (staphylococcal infection), sepsis ("blood poisoning" from bacterial toxins), and hospital gangrene (clostridium infection),[27] the hospital cross-contamination with infections remaining a problem to this day.[c] [28]

During the last three decades of the 19th century in Europe, intrepid surgeons such as Theodor Kocher, Theodor Billroth—himself a surgeon in the Franco-Prussian War—Jan Mickulicz, and Vincenz Czerny developed, without formal precedent, the techniques of abdominal surgery. Their success was predicated on utilizing strict antiseptic principles in tandem with general anesthesia. The rate of postoperative infections dropped dramatically after employing carbolic acid for sterilization of surgical instruments, hands,[d] and the operative field. The science and general principles of elective abdominal surgery for disease processes—

c Hospital -acquired (nosocomial) infections remain a significant problem in modern medicine, and are due to endemic bacteria that and reside and spread throughout the hospital environment, infecting wounds, indwelling catheters, and urinary and respiratory systems. The CDC estimates 1.7 million such infections occur annually in U.S. hospitals, contributing to or causing approximately 99,000 deaths.

d Sterile rubber gloves were not conceived of at this nascent phase, and were initially conceived to protect hands against irritation from carbolic acid disinfectant.

particularly cancer—were laid down by these pioneer surgeons and others, yet surgery for abdominal trauma remained a stepchild, and nowhere more so than among the military establishment.

It was, of course, well known after centuries of experience that the mortality rate for penetrating wounds of the abdomen, especially GSWs, treated by expectant management was consistently around 70-80%.[29] That still left one out of five wounded who recovered from abdominal trauma without the meddling of the surgeon. On the other hand, the few cases of abdominal surgery for trauma attempted in the 19th century had a similar mortality rate. The poor results for surgical intervention may be attributed to several factors.

First of all, antiseptic technique was slow in gaining broad acceptance, especially among the older and conservative surgeons, following its introduction by Lister. Secondly, few surgeons at that time had adequate training or experience in abdominal surgery, as it was rarely attempted prior to antiseptic technique. Even then, as late as 1890 in a major English hospital, "To open the abdomen was an event."[30] It must be mentioned that physicians in that era possessed an exquisite knowledge of human anatomy, perhaps surpassing that of the current medical student and physician.

Lastly, and as importantly, it was not appreciated until the First World War that the longer the delay in operating on abdominal wounds, the greater the mortality from hemorrhagic shock, subsequent peritonitis, and sepsis. Consequently, up through the first year of WWI, surgery on penetrating abdominal trauma was often delayed beyond the point of a potentially successful outcome. Shock at the time was not recognized as being directly associated with progressive blood loss, and fatal leakage from perforated bowel was thought an infrequent consequence of GSWs, having no direct relationship to peritonitis or sepsis.

The eminent Victorian surgeon, Sir William MacCormac, became Surgeon-in-Chief in 1875 of the Anglo-American Ambulance which served during the Franco-Prussian War (1870-71). He observed during the war that, "Of penetrating wounds of the abdomen we saw but a few, and the subjects of these died rapidly of peritonitis and shock."[31] Undoubtedly, the majority of such injuries died in the field from hemorrhagic shock before ever reaching a medical facility. Following the two-month siege of Metz, MacCormac reported, "As might be anticipated the penetrating abdominal wounds were all fatal. The four cases of wounds of the pelvis all recovered, as the abdominal cavity was not implicated."

MacCormac was opposed in this nihilistic view by American surgeon James Marion Sims, who pioneered the repair of vesico- and rectovaginal fistulae. Sims, who was from South Carolina, left for England during the American Civil War and led the Anglo-American Ambulance in the Battle of Sedan (1870). In the 1880s, Sims advocated for early surgical intervention for GSWs to the abdomen.[32]

Concomitantly, surgery for abdominal trauma was championed by another American surgeon, George Goodfellow. a pugilistic polymath and gifted surgeon who found his calling in the Wild West that was Tombstone, Arizona Territory. In 1881, the same year that President Garfield was shot in the abdomen in an assassination attempt, Goodfellow operated on a miner with multiple intestinal perforations from a GWS similar to Garfield's. The miner lived, Garfield did not.[33] Goodfellow went on to operate on Virgil and Morgan Earp after both were shot during the O.K. Corral gunfight later that year, and subsequently operated on many GSW cases, including those to the abdomen.[34] Goodfellow consequently became the expert and chief proponent in the United States of abdominal surgery for GSWs. Later, he promulgated his experiences with abdominal trauma surgery as an U.S. Army surgeon in the Spanish-American

War,[e] advocating for early surgery using aseptic technique in managing abdominal gunshot wounds (GSWs).[35] Despite his successes and publications, the civilian and military medical establishments were reluctant to adopt Goodfellow's recommendations, convinced such efforts were ultimately futile.

The experience of the British in the Second Boer War of 1899-1902 did little to promote surgical intervention for abdominal trauma. Despite the monumental achievements during the prior three decades in elective abdominal surgery, the results of urgent surgical intervention in that war were disheartening. The statistics, poorly recorded and questionable to begin with,[36] were further muddled by the South African climate which was dry, the soil not conducive to the propagation of anaerobic bacteria that cause gas gangrene and tetanus.[37] Hence, infections from extrinsic sources such as clothing, dirt, and debris carried into the wound were far less frequent, further discouraging the impetus for urgent abdominal exploration. The presence and significance of massive intraabdominal bleeding requiring immediate surgery were still not recognized at the time.

Furthermore, in that conflict, only 207 penetrating abdominal wounds were officially reported among the British, most likely representing those who survived initial wounding in the field and transport to a field hospital, and not necessarily representative. Several surgeons attempted abdominal surgery on a total of 26 casualties, 18 of whom died, a nearly 70% postoperative mortality comparable to that of expectant management. On the other hand, two patients survived, most likely due to having undergone surgery. Moreover, equally inimical to the case for surgery were two army officers who survived their abdominal injuries without resort to operation.[38]

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e[7]Goodfellow, as US Army surgeon at the time, was involved in the negotiations that led to the treaty ending the Spanish-American War.

Consulting surgeon to the British Army in the Boer War was William MacCormac, the surgeon who had served in the Franco-Prussian War. He had initially espoused surgery for abdominal trauma and was also a strong proponent of antiseptic technique. Perhaps due to his negative experiences during the prior war, MacCormac was led following the Boer War to conclude in an unfortunate aphorism widely quoted, "In this war, a man wounded in the abdomen dies if he is operated on and remains alive if he is left in peace."[39] His stature among the English medical community was sufficient to dampen any efforts toward surgical intervention for trauma. Considering the establishment of efficacious abdominal surgery in the civilian sector, the limited results from the Boer War represented tragically "missed opportunities" in developing a rigorous surgical approach to the management of abdominal penetrating wounds.[40]

Consequently, among the majority of surgeons and nations preceding WWI, the accepted treatment of abdominal trauma, including GSWs, was conservative and expectant. The regimen became standardized and consisted of placing the patient in a Fowler position (semi-supine, knees up), a more comfortable position that allowed blood and fluids to collect in the pelvis for easier surgical drainage; maintaining body heat and core body temperature, as one of the hallmarks of the shock syndrome was marked cooling of the skin and extremities;[f] nothing by mouth for three days, since the gut ceased function (ileus) secondary to injury; the administration of morphine; and rectal or subcutaneous saline infusions to combat dehydration.[41] [42]

One school of thought even held that perforated bowel was capable of healing spontaneously, speciously presuming that GSWs from modern "pointed" bullets caused solitary,

[f] The cause of marked hypothermia in hemorrhagic shock, apart from prolonged exposure in the field prior to transport, was unknown at the time. It was subsequently discovered to be due to marked vasoconstriction to the skin, muscle, kidneys and gut by circulating hormones and the sympathetic nervous system reacting to decreasing blood pressure and volume. This evolutionary neuroendocrine response redistributes remaining blood and oxygen/glucose to the heart and brain in humans as a last-ditch effort to sustain life.

clean perforations to intestine that were self-sealing. A major theory was that the current "humane" metal-jacketed conical bullets produced far smaller entry wounds and trauma along their paths through the body, especially at distance, than the lead musket balls of the past, allowing for hollow viscera like intestine to heal spontaneously.[43] [44]

The basis for this conclusion was, in part, a series of experiments on dogs by a leading French surgeon, Jean Paul Réclus. Producing perforations in the intestine—which were hardly comparable to a GSW—he observed that the leaking bowel was occluded by protrusion of its mucosa lining, and by inflammatory adherence to adjacent bowel, effectively sealing the perforation.[45] It was concluded that exploring the abdomen only broke up the natural adhesions that had effectively sealed the perforated bowel. Clinical observations utilizing expectant management during the Sino-Japanese War of 1894-95, the Spanish-American War, and the Tirah Expedition of 1897-98 did little to contradict the theory of spontaneous intestinal healing.[46]

At the turn of the 19th century, two opposing schools thus developed regarding surgery for abdominal wounds: the smaller group of interventionists, primarily in America and Germany, who endorsed early surgery; and the abstentionists, the larger group represented by the French and English, who endorsed expectant management.[47] In the United States prior to WWI, options for managing abdominal wounds were more openly debated. The argument for early surgery was proposed but not taken up, the conclusion being that surgery was not feasible or efficacious in the context and exigencies of war, particularly the difficulties of transport from the front lines and the volume of wounded presenting to medical staffs.[48] Thus, the prevalent theory among the Allies, the Central Powers, and their medical services upon entering WWI was that a penetrating wound to the abdomen would have a better chance of survival if managed expectantly rather than with surgery, commanding far less resources for an otherwise hopeless enterprise.

In a series of lectures, the influential French military surgeon, Edmund Delorme, gave "surgical advice" based on his experiences in the Balkan Wars and a review of the literature.[49] Published in 1915 as *War Surgery*, he inveighed against the current predilection for more aggressive surgery, particularly when it came to war wounds to the abdomen. "If we discuss the opportunities for *extensive laparotomy* [author's emphasis] in wounds of the abdomen and intestines in ordinary everyday practice, we find they are not at all the same in war surgery. *As a principle, immediate laparotomy* should be rejected." [50] In his opinion, attempts at surgical intervention were wasteful of time more profitably spent on other types of injury, that surgery increased shock and destroyed "beneficial adhesions," and promised poor outcomes.[51]

Instead, Delorme promoted a technique introduced by Chicago surgeon John Benjamin Murphy, a pioneer in abdominal surgery techniques. After a patient with penetrating injuries to the bowel had been placed in a Fowler's position and given morphea, Murphy proposed a limited incision under local anesthesia in the abdominal midline just above the pubic bone to drain "septic fluid" (pus) from the pelvic cavity. Murphy stressed that a patient with peritonitis, unable to take nourishment by mouth, needed instillation of copious fluids per rectum (proctoclysis) to restore bodily fluid balance.[52] Murphy, in fact, was addressing a situation—decades before the discovery of antibiotics—where the patient had already developed peritonitis and an abscess collection after a trial of expectant management, rather than one of acute penetrating abdominal trauma.

A major exception to such fatalistic, erroneous doctrines was developed in the Czarist Russian Army Medical Corps during the Russo-Japanese War (1904-5). This medical precedent was initiated by Vera Gedroitz, a Lithuanian princess related to the Radziwills. Gedroitz was the first woman surgeon in Russia, a poet, and one of the first women professors of surgery in the

world. While she served as a military surgeon for the Russians during that war, she achieved remarkable success by aggressively operating on penetrating wounds of the abdomen. Within a six-month period, Gedroitz performed 168 laparotomies for trauma. A corollary observation of hers was that the closer the field hospital was located to the front, the higher the survival rate of the severely wounded.[53] [54] [55] [56] Her surgical approach, though never published by her *per se*, was nonetheless adopted by the Russians upon their entry into the First World War, at which time Gedroitz was in charge of the Russian Red Cross hospital trains.[57]

Despite her successful surgical outcomes for abdominal trauma, reports of her results were at first largely ignored in the West.[58] This was likely due to several reasons: conservative attitudes of the surgical hierarchy; bias toward Russia, the Bolshevist movement, and women in general; and that Gedroitz was openly gay, audaciously wearing men's clothing in public. In a 1917 paper, the renowned British military surgeon of the Boer War and Great War, Cuthbert Wallace, grudgingly referred to Gedroitz as a surgeon in the Russo-Japanese War who had "met with some measure of success."[59]

The prodigious challenges of trauma, infection, and shock were already recognized by the early months of the Great War, a conflict initially predicted to last several weeks at most. It has been estimated that there were over 30 million casualties on all sides in the First World War, including eight to nine million combat deaths, both Killed In Action (KIA) and Died Of Wounds (DOW).[60] [61] [62] The British Empire suffered 3 million military casualties, of which almost a million were combat deaths. The BEF data recorded 40,000 casualties recovered from the field with abdominal wounds. Based on medical records of the British Expeditionary Force (BEF), 1.92% of all injuries transferred from the field consisted of penetrating abdominal wounds, extrapolated to perhaps close to 500,000 casualties having sustained abdominal wounds among

both Allied and Central Powers. However, at the Allied Casualty Clearing Stations (CCS), the incidence of abdominal trauma was only 0.72%.[63] The implication is that, apart from the unlikelihood of misdiagnosis in the field, 62% (25,000) of soldiers with abdominal wounds died en route to definitive medical care. It must be kept in mind that these statistics represent those who initially survived an abdominal injury in the field. A significant number, one that has been much debated but never been firmly established, undoubtedly died before receiving formal medical attention, in other words killed in action (KIA).

The French at the onset of the war estimated that 13-14% of wounds sustained on the battlefield resulted in abdominal wounds, decreasing to between 7 to 10% of all injuries reaching ambulances and medical aid.[64] Far fewer surviving abdominal injuries eventually reached the base hospitals to the rear. It was subsequently acknowledged that these statistics were incomplete and suspect, in need of verification and revision.[65] Abdominal wounds were often more lethal that head wounds,[66] a result of acute hemorrhage or subsequent peritonitis, and approximately half of all abdominal injuries were concluded to be penetrating. German estimates for the incidence of penetrating abdominal wounds ranged from 15 to 25%, though it was recognized that determining accurate data was impossible due to the contemporary nature of combat and of wounding.[67] More recent estimates for major abdominal wounds averaging 2.2% of all wounds sustained in WWI, again an imperfect statistic at best, and likely skewed by those wounded who survived long enough to receive medical attention.[68]

The cause of such destructive injuries and polytrauma (multiple injuries incurred simultaneously by an individual) was the extensive trauma produced by the ballistics of modern arms and of shells and shrapnel. The high explosives rendering such destructive force were developed primarily by Swedish chemist and industrialist, Alfred Nobel. During the course of the

war, for example, one medical attendant noted, *"*A stoic fellow contemplates his eventration [disembowelment] without a gesture; under his shirt, a fluctuation, sticky, liquid, alive and warm, stomach, intestines... A bandage is placed on top, and he's carried off."[69]

The principle rifles of the Allies were the Lee-Enfield .303, Lebel & Bertheir 8mm, Mannlicher-Carcano 6.5x54 mm, Mosin-Nagant 7.62x54 mm, and Springfield 1903 .30-06; among the Central Powers were the Steyr-Mannlicher M95 6.5x54mm, and Mauser M986 G. The average muzzle velocity of these rifles was around 2,400 ft/sec. Far more devastating were the Maxim and Spandau machine guns used by the Central Powers, and the Vickers, Lewis, and Browning machine guns by the Allies. Statistically as devastating to ground troops were the high explosive shells, shrapnel shells, bombs and grenades, and trench mortars introduced in that war, designed to explode on contact or high overhead of entrenched soldiers. The average initial velocities of shrapnel from these shells was between 4,700-6,700 ft/sec, with internal bodily damage (blast injury) also sustained from the shock waves of high explosives.[70]

The distribution of fragmenting shell and shrapnel is obviously indiscriminate, with extremities by virtue, in part, of body surface area sustaining the highest proportion of injuries accounting for between 54-65% for the wars of the last century to the present.[71] [72] The most common abdominal organs injured during WWI in one English study of 300 penetrating abdominal wounds were: 96 small bowel injuries (32%), 85 colon (large bowel) injuries (28%), 33 liver injuries (11%), 29 renal (kidney) injuries (9.6%), 24 gastric (stomach) injuries (8%), 14 splenic injuries (4.7%), 14 bladder injuries (4.7%), and 10 rectal injuries (3.3%).[73] The etiology of penetrating abdominal wounds involving abdominal organs were evenly distributed between bullets and shell/bomb fragments, with the exception of bullets as the chief cause of rectal

injuries.[74] German data was comparable.[g] [75] Many cases of abdominal trauma had wounds to multiple abdominal organs, including combined chest and abdominal (thoracoabdominal) injuries.

Logistics under fire from the start of the war was a significant issue in the management of trauma, especially concerning abdominal trauma. Penetrating injuries often caused massive intrabdominal bleeding and shock requiring expeditious transport, along with time-consuming surgical exploration of the abdomen. Early data from the French suggested that definitive medical attention given to the wounded within the first several hours after wounding markedly reduced mortality, introducing the concept of the "Golden Hour," [76] a conclusion already arrived at by more experienced surgeons like Gedroitz. Recognizing the direct relationship between increasing mortality and delay in treatment, the English/Anzacs, French and Russians, like the Germans and Austrians, initiated a linear system of triage and progressive medical station transfers of the wounded.

Such a system was enabled by the static conditions associated with trench warfare in Western Europe—more difficult in the East, Africa, and Gallipoli. First in the transport chain were the Regimental Aid Posts (RAPs) manned by two physicians and several orderlies situated directly behind the front lines, along with sixteen to thirty-two stretcher bearers. The RAPs ranged from dugouts, shell holes and trenches, to formal bunkers and abandoned houses. As would be surmised, the staff at these RAPs sustained significant morbidity and mortality.[77]

The walking wounded with minor injuries—up to 40% of casualties—were returned to the front after treatment. More serious wound cases were stabilized and sent from there to the Battalion Aid posts and field ambulance main dressing tents for triage, then on to Casualty

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g[75]Large and small bowel injuries, 60.9%; liver injuries,16.1%; gastric injuries, 7.3%; renal injuries, 7.3%; Mesentery and blood vessel injuries. 5.0%; spleen injuries, 2.7%; pancreatic injuries, 0.4%.

Clearing Stations (CCS) just beyond the range of enemy artillery, usually about six miles behind the Front. Transport to these rearward areas was provided by horse-drawn and by motorized ambulances. The average time from battlefield to CCS was on the order of six to ten hours, though it could be as brief as thirty minutes,[78] or take several days if one was unfortunate enough to lie in a water-filled shell crater among the dead in No Man's Land.

The CCS became areas of definitive surgical care, as urgent surgical intervention (what is now termed "damage control") was progressively carried nearer to the Front. Eventually, a number of the CCS's were assigned solely to the management of abdominal trauma, as were CCS's which were principally reserved for head injuries. It must be stressed that in WWI, the only diagnostic evaluations of abdominal trauma available to the surgeon were the patient's symptoms, the physical signs on examination, and x-ray equipment at rearward facilities for location of metal fragments and fractured bones. As in the American Civil War, proof of perforated bowel on occasion would be announced by the emergence of an Ascaris parasite worm through the wound. Follow-up care and any further surgeries were accomplished at stationary "fixed" hospitals, the Base Hospitals and hospitals in the homeland.

Rapid access to medical care alone did not suffice for managing severe wounds. Concomitant medical advances were necessary for improving the survivability of major trauma, especially injuries to the abdomen. The foremost of these involved the administration of fluids and blood transfusions for those in or about to enter the shock state. The physiological explanation for shock syndrome associated with severe blood loss would not be elucidated until several years after the war. Surgery of itself was thought to induce shock, especially during the induction of general anesthesia.[79] However, soon into the war, it became apparent that infusing fluids and blood to the wounded resuscitated their vital signs (blood pressure, heart and

respiratory rate). The infusions of "saline always bucks a patient up a little,"[80] and improved their ability to undergo surgery, significantly increasing the overall survival rates. Secondly, though antiseptic technique by now had been universally adopted, the incidence of tetanus and gas gangrene—caused by the *Clostridia* genus of bacteria—was significant. These lethal infections were due to highly-manured farms/battlefields of Western Europe. The use on both sides of anti-tetanus serum, developed over a decade earlier, dramatically reduced the incidence of tetanus in the first months of the war.[81]

Faced with the unacceptable prognoses associated with expectant management, some British surgeons in the British Expeditionary Force (BEF) attempted emergency laparotomies in the CCS and the base hospitals to the rear. One of the first to do so was Owen Richards, who had been appointed Professor of Clinical Surgery at the Egyptian Government School of Medicine in 1905. While there, Richards developed a particular interest in abdominal surgery, experimenting with bowel surgery using cows as subjects.[82]

When war broke out, Richards resigned his post in Cairo and entered the Royal Army Medical Corps (RAMC). In 1914, he was attached to CCS 6 in Arras, France. There, he persuaded Sir Anthony Bowlby to consider surgical intervention for abdominal trauma. Bowlby was chief consulting surgeon to the BEF, and he had been senior surgeon at Portland Hospital in Bloenfeld, South Africa, during the Boer War. Bowlby held the strong opinion that early surgical intervention was paramount in the management of trauma for nonabdominal types of wounds, and agreed to let Richards try abdominal surgery near the front lines.[83]

Within several months, Richards had operated on nine patients with abdominal wounds, only two of whom survived. He published his clinical results in his paper, "The pathology and treatment of gunshot wounds of the small intestine," in 1915.[84] Despite the discouraging results,

his report attracted considerable attention. This was due not only to the detailed descriptions of each case, but the survival of two officers who had sustained multiple small bowel injuries.

By that point, the delusory concept that bowel injuries were self-healing had been largely abandoned, replaced by a pessimistic assumption that such injuries were uniformly fatal. Richards proved them wrong, notwithstanding Gedroitz's earlier paper on her successful experience with laparotomy for abdominal trauma. Richards went on to validate the paramount importance of time to surgery after wounding, the necessity of available and experienced surgical teams, proper selection of patients for surgery, and the optimal procedure for any given injury.[85]

Cuthbert Wallace, the respected British surgeon who had served in the Boer War at Portland Hospital with Anthony Bowlby and now in the Great War, became familiar with Owen Richards' work. At this conjuncture, a number of English and French surgeons attempting laparotomies for penetrating wounds had become discouraged by their poor results. Possibly, hesitancy in operating on asymptomatic bowel injuries, temporarily sealed by the formation of intraabdominal adhesions, led to a false sense of security until peritonitis and sepsis set in. Nevertheless, based on Richard's report and his own experience, Wallace was able to convince BEF Surgeon General William MacPherson to allow a limited clinical trial whereby some of the field ambulances would send abdominal casualties directly to the CCS for evaluation and potential surgery.[86]

It was alleged that prior to formal approval, Wallace was already smuggling surgical instruments for laparotomies to CCS units he felt were suitable for undertaking such an enterprise.[87] By May 1915, clinical and autopsy results were compelling enough for MacPherson to hold an inquiry into the causes of death in abdominal trauma resulting from modern weapons. Based principally on Wallace's clinical data and autopsy findings, MacPherson mandated in early

June 1915 an official policy in the BEF that major and penetrating abdominal wounds were to be immediately evacuated to a CCS for surgical evaluation and intervention.[88]

Wallace established from his surgeries and autopsies that all deaths from acute abdominal wounds were due to massive hemorrhage due to disrupted intrabdominal and pelvic vasculature. Expectant management, Wallace concluded, wrongly focused on intraabdominal infections and peritonitis, events that occurred days after injury. Rather, he argued that attention should be directed toward urgent surgical intervention for control of ongoing acute hemorrhage and repair or removal of injured bowel. He further demonstrated that the velocity of modern firearms, contrary to prevailing opinion, caused extensive tissue wounding, and usually multiple as opposed to single perforations of the gut as well as damage to adjacent organs.[89]

From 1915 onward, military surgeons in England, France, and Germany sought to improve the surgical management of abdominal trauma. In April 1916, H.H. Sampson (RAMC) had garnered enough experience with operating on abdominal trauma to publish his results, reinforcing the conclusions of Richards and Wallace. Indeed, massive bleeding was the cause of the majority of acute deaths, and ensuing peritonitis from leaking bowel and abscesses had a high mortality rate. Expedient transport to a medical facility and emergency surgery resulted in the highest likelihood of survival. Though Sampson reported on only eight cases, all survived.[90]

Within ten months of official sanctioning of laparotomy for abdominal trauma, several papers were already published on the subject by surgeons among all major belligerents. One of these was Sir Gordon Gordon-Taylor, who would become a preeminent surgeon in England after the war. He served in France during WWI, and helped develop criteria for the evaluation and treatment of abdominal injuries. Surgeon-researchers John Fraser and H.T. Bates reported on their own extensive series of abdominal surgeries, published in April 1916. They had by then

operated on 54 of 65 soldiers with abdominal trauma, finding that small bowel and large bowel (colon) injuries were the most common, rectal and spleen injuries being infrequent. Overall mortality after surgery was 50%, with the highest mortality associated with rectal and bladder injuries, the lowest with liver, kidney and spleen injuries.[91]

Concomitantly, the German military surgeons arrived at the same conclusions. At the outbreak of the war, a similar conservative dictum held among them that, "Sometimes small intestinal holes healed without surgery, and subsequently the doctrine arose that laparotomy in the field is a mistake. Better insight and better surgical training of our field physicians have taught us to overcome this point of view today, and so one of the greatest changes that the World War has created for us physicians is the fact that we have become more aggressive with respect to abdominal gunshot wounds."[92]

Straightforward indications for abdominal surgery soon became codified among all major army medical services. Indications included the hemodynamically unstable patient, but who was not in the later stages of shock; the likelihood of perforating abdominal injuries, especially with GSWs; the presence or onset of abdominal rigidity; and, increasing abdominal pain—indications which remain pertinent in trauma surgery.[93]

With further experience, relative but pragmatic contraindications to surgery were proposed which included eminent death; a hemodynamically stable and asymptomatic patient; a right upper quadrant (RUQ) abdominal injury involving the liver in an otherwise stable patient; a combined left upper quadrant (LUQ) abdominal injury with a chest injury (subsequently refuted); an interval of time from injury to medical care greater than 24 hours; and profound shock indicated by a pulse rate greater than 120 per minute.[94] Liver injuries, then as now, in a stable patient were often best treated expectantly, while all combined thoraco-abdominal injuries

are currently managed surgically. A time interval to medical care greater than a day was associated with a very poor prognosis, likely due to Class II-IV shock with its associated physiological derangements, and incipient infection/sepsis. In the presence of such profound shock, surgical mortality was increased by 50%, and required resuscitation of the patient with fluids and blood transfusions before surgery could be reasonably attempted.[95]

Consequently, a proper sequence of preparing the patient for abdominal surgery was devised.[96] A priority was the initiation of warming the patient as soon as feasible with hot water bottles, stoves—even directing heated air from the engine compartment of a motorized ambulance into the passenger cabin during transfer—and warm saline infusions given subcutaneously, intravenously (IV), or per rectum. If shock intervened, the patient was placed in Trendelenburg (head-down) position, with the administration of saline, acacia gum (colloid) solutions, and blood transfusions. The anesthetic of choice was a mixture of ether and nitrous oxide termed balanced anesthesia, though sometimes spinal anesthesia was used. Intravenous bicarbonate solutions were given if the patient became acidotic as a result of shock and hypoperfusion of tissues.[97] [98] In dire circumstances, the judicious administration of one milligram of pituitary extract was recommended by Fraser. The pituitary extracts contained epinephrine, among other hormones, and could stimulate the cardiovascular system in the severely wounded patient about to undergo surgery.[99]

Eventually, principles of trauma care became more defined. These included the absolute imperative for arrest of hemorrhage and its role in mitigating postoperative infections; the high mortality accompanying subsequent peritonitis and intraabdominal infections; the frequency of multiple associated injuries; and that intrabdominal injuries could occur in association with chest, buttock, and back wounds. Most importantly, perhaps, was the necessity for a thorough

exploration in every case of penetrating abdominal trauma, lest other injuries be overlooked. Recommendation was for a generous midline incision to enable full exploration of the abdomen in penetrating wounds, a sound principle which remains the linchpin for current abdominal exploration for trauma.[100] The resulting CCS medical records specifically of abdominal trauma provided the most complete and extensive wound treatment data of the war. The data was essential to the BEF Medical Research Committee charged afterward with an analysis of military medicine in the First World War.[101]

Interestingly, operative and autopsy findings often demonstrated tissue damage or necrosis well away from the tract of the bullet, and a number of theories were proposed to explain tissue damage at a distance. Temporary cavitation of soft tissues and (controversial) hydrostatic pressure waves caused by the kinetics of the bullet's mass and velocity were unknown at the time.

As the war progressed, the determinants associated with successful surgical outcomes became clearer. Unequivocal validation was established concerning the need for speedy transport of the wounded, preservation of core body temperature, and prompt laparotomy. In addition, an imperative was the presence of an experienced surgical team with an operating theater available at all hours. Moreover, the facility had to possess the ability to continue treatment of the patients postoperatively until stable. Another factor influencing surgical outcome was the number of incoming casualties, large numbers potentially overwhelming resources of time, supplies, and surgical personnel. Under such circumstances, the CCS would close, with diversion of casualties to a nearby CCS. Gordon-Taylor specifically inveighed against the "surgical sluggard" who wasted precious time in performing what should have been an urgent surgery for stemming hemorrhage and bowel leaks.[102] Of interest, the recommended dose of

morphine administered during transport was a half grain (32.5 milligrams) given intramuscularly. This same dosage was used in the Second World War until it became apparent that this amount of morphine not infrequently led to respiratory arrest and death.[103] Currently, a third to a quarter of this dose is routinely used for acute pain management, along with ketamine in the field.

The best prognosis, not surprisingly, was found to be associated with minimal small bowel wounds requiring only simple suture closure of perforations, as opposed to resection of heavily contused bowel with multiple massive perforations. The worst prognosis was seen in combined thoracic and abdominal wounds. Wounds to the upper abdomen had better outcomes than those to the lower abdomen sustained below the level of the umbilicus. Abdominal wounds due to high velocity bullets, shell fragments and shrapnel had a significantly greater mortality than those due to lower-velocity grenades and bomb fragments.[104] [105]

In addition to their clinical duties at the Front, John Fraser and Hamilton Drummond[h] performed a series of surgical experiments on rabbits during the war to determine the optimal methods of repair of intestinal injuries. Their findings were employed in the management of 300 perforating wounds of the abdomen, with both their experimental and clinical results published in 1917. In their series, the highest mortality rate, 70%, was associated with rectal injuries, most likely due to associated pelvic structure injuries and peritonitis due to the lack of antibiotic therapy. The lowest mortality rate, 35%, was seen with splenic injuries, which were treated with either repair for simple lacerations or splenectomy for more extensive disruption. The overall surgical mortality rate for penetrating abdominal trauma was approximately 50%, still significantly less than the over 80% mortality seen with expectant management. [106]

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h[7] The Marginal Artery of Drummond is named after his physician father, Sir David Drummond. Hamilton, a promising young surgeon, was killed soon after the war in a motor vehicle accident.

The Germans reported a mortality rate for abdominal surgery of 67% for intestinal perforations (Haenel), 56% for gastrointestinal injuries in general (Enderlein and Sauerbruch), and 50% for all primary operated cases (Läwen).[107] Since there was no strict stratification of organ system and severity of injury or specific treatments and outcomes, direct comparisons of data between various authors and between Allies and Central Powers is problematic.

At the conclusion of the war, abdominal trauma surgery had been firmly established, though the abdomen was considered "still more or less an unknown region in surgery."[108] The young surgeons of the First World War and their mentoring elders innovated abdominal surgery and management for trauma as their Clearing Stations flooded with the wounded, few precedents available for them to follow. Yet, in his 1918 book *The Early Treatment of War Wounds*, Scottish surgeon M.W. Gray intentionally excluded a discussion of abdominal trauma, stating in his preface, "A surgeon who has mastered the technique of successful excision of an ulcerating cancer of the colon is capable of obtaining as good results as possible if he applies the same principles in the treatment of war wounds of the abdominal organs. . ."[109]. In fact, he acknowledged that, "the surgeon fresh from civil practice. . . will speedily find that war wounds in France behave very differently from those to which he is accustomed at home. . ."[110]

An earlier, and contrarian, admonition was given in 1875 by William MacCormac in his recollections of the Franco-Prussian War, writing, "The author is satisfied that errors may be committed by being too exclusively guided by the experience gained in civil hospitals."[111] In 1946, the pioneer heart surgeon Michael DeBakey, following his vast compilation for the U.S. Army of medicine in the Second World War, put it succinctly. "All the circumstances of war surgery thus do violence to civilian concepts of trauma surgery."[112] Most recently, a retrospective study of Forward Surgical Team Experience (FSTE) among American troops in Iraq and

Afghanistan concluded, “Training programs and years of general surgery practice do not replace FSTE among military surgeons.”[113]

The physicians and surgeons of the First World War, often civilian practitioners, rapidly adapted to new and unexpected contingencies requiring novel thinking, algorithms, and approaches to war trauma. These men and women sought to rectify the unacceptable mortality for abdominal trauma in a military medical culture where expectant management was the norm. By force of experience and clinical data, they were able to dramatically change the theory and practice of the military medical establishment among all major belligerents, rejecting the pessimism attending the prognosis of abdominal injuries. Trauma surgery was often literally innovated under fire, based on surgery that had evolved only within the preceding three decades. In doing so, they implemented the most recent scientific and medical breakthroughs to achieve lower mortality rates. The initial mortality of penetrating abdominal trauma decreased from 70-80% with expectant management to as low as 35-44% with surgery at the conclusion of WWI.[114]

Twenty-one years after the armistice that ended the “war to end all wars,” Gordon-Taylor published *The Abdominal Injuries of Warfare.* It was a compilation of his experiences and those of his colleagues in the Great War, lessons learned that were soon passed on to the next generation of surgeons about to enter the Second World, and subsequently to the current generation of military personnel in current conflicts. Trauma surgery has continued to evolve, based on the foundation of those lessons. The fundamentals of medical management for the future were established, allowing for current overall mortality rates following wounding of around 10%, despite the greater incidence of polytrauma (multiple trauma per patient) and the severity and lethality of modern weaponry.[115] The First World War, whether fortuitously or not, was to be the crucible of that evolution.

Conclusions: Abdominal surgery for trauma was inconceivable before the advent of landmark scientific and technological advances in the 19th century, contingent primarily on the introduction of general anesthesia and antiseptic technique. Despite major strides in abdominal surgery in the civilian sector prior to WWI, the majority of military medical establishments regarded surgery for penetrating abdominal trauma as futile, impractical, and unnecessary. The multifactorial reasons included decisions based on imperfect conclusions dependent on inadequate clinical data, bias, and misleading research. In addition, outcomes in previous conflicts with abdominal surgery were discouraging, as the relationship between surgical outcome and the time from wounding to medical management was not recognized. Moreover, peritonitis was thought to be caused by inflammation, not bacterial infection from leaking bowel, and acute hemorrhage was not identified as the chief cause of death in penetrating trauma. The concepts of hemorrhagic shock and its treatment were not well understood. A conservative and rigid mindset among the medical and military communities assumed that the success of abdominal surgery in the civilian sector could not be replicated in the war setting, where proximity to the front lines and volume of trauma cases was assumed to make expedited surgery impractical. Within a year of the commencement of WWI, however, the high mortality rates associated with abdominal wounds necessitated new strategies, mandating surgery for penetrating abdominal trauma within several hours of wounding. Favorable surgical outcomes required rapid transport of the wounded from field to hospital, preoperative resuscitation of the patient with fluid and blood transfusions, and application of strict antiseptic techniques. In the process, the foundations for modern trauma surgery were established by physicians and leaders willing to challenge the status quo of longstanding military and medical dogmas.

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