The Symbiosis of Combat Casualty Care and Civilian Trauma Care: 1914–2007

Basil A. Pruitt, Jr, MD, FACS, FCCM

J Trauma. 2008;64:S4–S8.

During the past century, wartime surgical experience and military medical research, principally that conducted in the U.S. Army Medical Corps and the U.S. Navy Bureau of Medicine during both war and peace, have combined to improve combat casualty care. Many of those advances have had direct application to civilian trauma care. Conversely, advances in technology and patient care in the civilian surgical community, often based on the results of clinical and/or laboratory research, have been readily adopted by the military to improve the care of casualties. The symbiosis between combat casualty care and civilian trauma care has accelerated surgical progress not only in the care of injured patients but other patients as well.[1] The velocity of that progress over the past century has been increased by the ever greater availability of specialty-trained board-certified surgeons whose experience enabled them to overcome military medical dogma and even ignore directives and Circular Letters, mandating specific care for limb and abdominal injuries, issued by the Surgeon General of the U.S. Army in 1943. Improvements resulting from planned research, which was conducted in the theater of operations for the first time during World War I, were largely initiated and directed by volunteer or drafted surgeons and other physicians with strong academic background and extensive research experience. Traffic in the other direction has brought the benefits of surgical techniques and skills gained in wartime surgery to the victims of urban violence and provided experience-based support for the development of trauma systems and centers.

There are four areas in which remarkable progress in the past 93 years has improved the outcomes of patients injured in each successive conflict from WWI to the current conflicts in Afghanistan (OEF) and Iraq (OIF). Those areas include wound care, control and correction of blood loss, prevention and treatment of organ failure, and organization and delivery of surgical care.

In addition to research activities initiated by individual investigators during each conflict in the 20th century, designated units conducted research in the theater of operations (Table 1). In World War I, General J.M.T. Finney, the Chief Surgical Consultant for the AEF and longtime associate of William Stewart Halsted, established a central laboratory and organized an Experimental Surgery Department within that laboratory under the direction of Major Walter B. Cannon of homeostasis fame. The tradition of in-theater integrated clinical/laboratory research was continued in World War II when Colonel Edward B. Churchill, Surgical Consultant of the North African-Mediterranean Theater of Operations and later the Chief of Surgery at the Massachusetts General Hospital, organized the Board for the Study of the Severely Wounded, in the Korean conflict by the Army Medical Service Graduate School Surgical Research Team organized by Colonel William S. Stone, and in the Vietnam conflict by the Trauma Study Section of the U.S. Army Medical Research Team in Vietnam, a unit of the Walter Reed Army Institute of Research.

There have been no designated research units in the theater of operations during any of the conflicts since Vietnam. A tentative step to correct that deficiency and the associated loss of research opportunities has been recently made with the assignment of research personnel from the Institute of Surgical Research to medical treatment facilities within Iraq. Additionally, since 1947 integrated clinical/laboratory research has been continuously conducted at the U.S. Army Institute of Surgical Research, the results of which have revolutionized burn care with unprecedented reduction in mortality and improvement in the outcomes of burned soldiers. Those advances have been transferred to civilian trauma care in the form of current methods of wound care, physiologically-based fluid resuscitation regimens, organ-specific surgical critical care, and the development of regional hierarchical systems of care delivered in trauma and burn centers.

WORLD WAR I

At the beginning of World War I, soft tissue wounds were treated much as they had been in the Spanish-American War, i.e. with occlusive antiseptic dressings. Both Spanish and American surgeons from that conflict reported that laparotomy for penetrating abdominal wounds was universally fatal, while 65% of American casualties treated nonoperatively with occlusive antiseptic dressings survived.[2 (p. 225)] Consequently, laparotomy for penetrating abdominal wounds was a controversial issue in 1914 and when employed, "was attended with a very high mortality" as reported by Colonel Charles Richard of the U.S. Army Medical Corps at the 1914 meeting of the Southern Surgical Association.[3] The failure of laparotomy was attributed by Cuthbert Wallace, a British

DOI: 10.1097/TA.0b013e3181645d77

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2008		**00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
The Symbiosis of Combat Casualty Care and Civilian Trauma Care: 1914-2007	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army Institute of Surgical Research (USAISR),3400 Rawley E. Chambers Avenue,Fort Sam Houston ,TX,78234-6315**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**5**	

Table 1 U. S. Armyintegrated Clinical/Laboratory Research Units in Theater of Operations: 1915–2007

I. WORLD WAR I
- A. Experimental surgery department of A.E.F. Central Laboratory
- B. Base Hospital 5: Neurosurgical trauma registry and data bank
- C. Casualty Clearing Station 48: Studies of response to blood transfusion

II. WORLD WAR II
- A. Board for the Study of the Severely Wounded
- B. Second Auxiliary Surgical Group: described "wet lung"

III. KOREAN CONFLICT
- A. Army Medical Service Graduate School Surgical Research Team

IV. VIETNAM CONFLICT
- A. U. S. Army Medical Research Team in Vietnam Trauma Study Section

V. OPERATION ENDURING FREEDOM/OPERATION IRAQI FREEDOM
- A. U. S. Army Institute of Surgical Research

surgeon, to delay between injury and operation.[4] In addition to delay in transfer to base hospitals, other limitations of the casualty care system were identified, prominent among which was the inadequate care provided by inexperienced surgeons performing, in the words of Dr. D. F. Jones, incomplete operations at the Casualty Clearing Stations.[5] The staffing of evacuation hospitals and mobile units with experienced surgeons to provide definitive care at the earliest possible time was advocated. Motorized ambulances, used for the first time in World War I, reduced the interval between injury and admission to a definitive treatment facility from 3 days to 12–18 hours.[6] Those changes, which permitted earlier surgical intervention, decreased the mortality of patients with penetrating abdominal wounds to a still daunting 45%, but from 1915 onward, laparotomy became the standard of care.[7]

At the 1918 annual meeting of the American Surgical Association, the Secretary read a letter from General J.M.T. Finney in which he emphasized the importance of surgical expertise. General Finney noted that he had an all-star cast heading the surgical specialties in the Army, including Major J. E. Goldthwait for orthopedics, Major Hugh H. Young for genitourinary disease, Major J. T. Kates for radiology, Major Harvey W. Cushing for neurologic surgery, Major V. P. Blair for maxillofacial surgery, and Major George W. Crile for research.[2 (p. 546)] Among those "stars", Major Cushing had more experience as a combat surgeon than anyone else on General Finney's staff. In 1915, Cushing had led a unit from Harvard Medical School that staffed a military hospital and motor ambulance service in Neuilly-Sur-Seine and for six weeks provided casualty care. Those activities enabled Cushing to organize Base Hospital 5 with great rapidity when U.S. Forces were mobilized and began operations in France in May 1917. Dr. Cushing operated upon thousands of men and kept extensive records on all. Those records formed what can be considered the first neurosurgical trauma registry and databank. Dr. Cushing favored removal of all intracranial foreign bodies and, to attain that goal, developed a magnet to remove metallic fragments from the brain.[8]

Dr. O. H. Robertson, who had been conducting research on the problem of anemia, enlisted in the Harvard Unit organized by Cushing. At Base Hospital 5, Robertson directed his attention to the problems of blood transfusion. He quickly developed an apparatus for transfusing blood and, by late 1917, had carried out transfusions with preserved "universal donor" (Moss Classification Group 4) blood. During the next year Robertson conducted clinical studies in the resuscitation ward of Casualty Clearing Station 48 and other casualty clearing stations in which he administered blood transfusions to casualties and recorded their beneficial responses.[9]

Cushing also developed a professional relationship with Alexis Carrel, a French surgeon and Nobel laureate, who developed an improved system for the antiseptic treatment of war wounds. Carrel, in collaboration with the English chemist Henry Dakin, developed a dilute solution of sodium hypochlorite and dichlormaine T, which was infused every two hours through catheters placed in the depth of the wound.[10] Such treatment, which prevented and treated wound infections and thereby reduced the rate of amputation of war wounded limbs, attracted the attention of the surgical community and a stream of visitors came to Carrel's hospital to learn his technic of wound care.

In the Experimental Surgery Department that General Finney organized in the AEF Central Laboratory, Crile and Cannon focused their laboratory studies on the problem of shock, the pathophysiology of which was poorly understood and attributed by many to stimulation of the "depressor nerve" and subsequent failure of the vasomotor center. The studies of Cannon and his colleagues in that laboratory directed attention to changes in the peripheral vasculature that followed hemorrhage and emphasized the importance of plasma loss, hemoconcentration, and the disproportion of vascular volume and residual blood volume as the aggregate effects of blood loss and increased capillary permeability. Those studies, published in a special report series of the Medical Research Committee of Great Britain in 1919,[11] formed the basis of subsequent work conducted between the two World Wars by Blalock, Phemister, Wiggers, and others that described the pathogenesis of hypovolemic shock and initiated the development of physiologically-based resuscitation.

WORLD WAR II

Care of the wounded was further improved in World War II as a result of the clinical experience and studies of individual surgeons and the planned studies by a designated research organization. General Fred W. Rankin, Director of the Surgical Division of the U.S. Army Medical Corps in World War II, extolled the use of improved methods of resuscitation, including a reliable supply of blood and blood products, the availability of antibiotics which were used for

the first time to prevent and treat infections in casualties, improved means of transportation to transfer patients over variable distances between various treatment facilities by vehicle, train, ship, or aircraft, and lastly, but perhaps most importantly, the availability of excellently trained surgeons who could perform surgery in combat areas. General Rankin considered those factors as being most important in reducing the morbidity rates for battle casualties and decreasing the mortality of casualties with penetrating abdominal wound to only 15%, a three-fold reduction from World War I.[12]

Five auxiliary surgical groups were used to overcome the relative shortage of highly qualified surgeons and were deployed as mobile teams to augment the surgical capability of any treatment facility as needed. The members of the auxiliary groups maintained detailed case records which documented improved outcomes and were used to develop early "evidence-based" policies for the management of casualties. Circular Letter #178, issued by Major General Norman Kirk on October 23, 1943, mandating exteriorization of large bowel injuries, represented an evidence-based policy appropriate for the Army trauma system, but unnecessarily restrictive when subsequently applied in civilian trauma care.[1] Dr. Lyman Brewer and the other surgeons on the thoracic surgery team of the second auxiliary surgical group described what was called "wet-lung in war casualties" which they considered to be a previously undescribed form of pulmonary edema, but may actually represent the earliest report of ARDS.[13]

The tradition of integrated clinical/laboratory research in the Army, begun by William Beaumont in 1822 and continued in the Central Laboratory in World War I, was maintained in World War II by the Board for the Study of the Severely Wounded organized in September of 1944. The physicians of that Board, which included surgeons, anesthesiologists, and pathologists, conducted studies of the crush syndrome, the general pathology of traumatic shock and the physiologic response to injury. They documented that lower nephron nephrosis was present in all of the patients who died with crush injury and that the infusion of hypertonic glucose or hypertonic saline solutions produced no beneficial effects in patients with renal failure. The Board raised the possibility that the occurrence of pulmonary edema in casualties with shock could be brought about or at least intensified by overenthusiastic intravenous fluid therapy, a concern which is receiving intense scrutiny today. The studies performed by the Board during the nine months of its existence were published as a separate volume in the series "The Medical Department of the United States Army in World War II".[14] In that volume, Colonel Churchill states, "Cobwebs of theory and hypothesis were swept away by simple observations and precise definitions. In the final phase systematic and precise measurements were made that for the first time described the actual physiologic state of the wounded man as it was observed on the field of battle". Several years later in 1953, Dr. Churchill, then Chief of Surgery at the Massachusetts General Hospital, noted the benefits of wartime surgical experience when he stated, "Patients in civilian disasters fare better when treated by the techniques of experienced war surgeons".[15]

KOREAN CONFLICT

Further advances in combat casualty care occurred during the Korean Conflict, again as a result of individual efforts on the part of surgeons, drafted into the Army and Navy, who applied their laboratory experience to advance clinical care, and the activities of the Surgical Research Team organized by Colonel William S. Stone, the commandant of the Army Medical Service Graduate School. A major advance was the direct repair of arterial injuries begun by Dr. Frank Spencer, General Carl Hughes, Dr. John Howard, and Dr. John H. Davis, which salvaged many limbs that would have previously been amputated.[1] Such repair of vessels was actually in contravention of Surgeon General Kirk's Circular Letter #178 of October 23, 1943 which declared, "Primary suture of all wounds of extremities under war conditions is never to be done. The guillotine or open circular method of amputation is the procedure of choice in traumatic surgery under war conditions."[15]

Further improvements in the organization of the trauma care system included the development of the Mobile Army Surgical Hospital and the first use of helicopters to transport casualties within the theater of operations (Fig. 1). Collectively those two innovations reduced the injury to admission interval to 4–6 hours and decreased the mortality associated with penetrating abdominal wounds to 8.9%.[16] An increased understanding of the pathophysiology of injury and shock led to more rapidly instituted and larger volume resuscitation regimens, which finally reduced acute renal failure to a low level in the latter years of the Korean conflict.[17]

Fig. 1. *The use of helicopters, as shown here, for the rapid transport of casualties from the site of injury to definitive care facilities was first begun by the U.S. Army in the Korean conflict. The patient was secured to a metal frame fastened to the outside of the helicopter. The red cross is affixed to the metal shield that protected the patient's head during transport.*

The Surgical Research Team instituted prophylactic hemodialysis in the theater of operations to minimize or avoid the complications of uremia in patients with renal failure. That team also identified high output renal failure as a more favorable form of renal dysfunction in combat casualties. Colonel Robert Lindberg, the microbiologist of the research team, identified seasonal variations in the predominant organisms causing infections in casualties – an early recognition of the constantly evolving microbial ecology of treatment units. Other team members, including Drs. John Howard and Curtis Artz, described changes in the coagulation system induced by injury and resuscitation, studied glucose metabolism and adrenal function in casualties, and described the hepatic response to resuscitation in the wounded.[1]

THE VIETNAM CONFLICT

In the Vietnam conflict, surgical care of the combat casualty was further improved by the abundant supply of certified surgical specialists and the application of technological developments represented by mechanical ventilators and physiologic monitoring devices, as well as the routine use of helicopters to reduce the time required for transportation of casualties to a definitive treatment facility (1.2–5 hours).[6] That rapid transport was associated with unprecedented survival of critically injured patients. The Vietnam Vascular Registry, established and maintained for many years by Dr. Norman Rich, has now been extended to include casualties from the current conflicts and provides a database which can be used to assess outcomes and develop practice guidelines.[18] Individual surgeons in Vietnam identified acute respiratory distress (called Da Nang lung by Navy surgeons) as a complication of severe injury and suggested that it might be related to excessive resuscitation.

The tradition of integrated clinical/laboratory research was maintained by the Trauma Study Section of the U.S. Army Medical Research Team in Vietnam. The changes in the volume and composition of gastric secretions in casualties and the effect of injury on circulating levels of hepatic enzymes were described by team members. The surgeons with the team also studied the hemodynamic and pulmonary changes and interactions that occurred in casualties.[19]

ADVANCES IN BURN CARE

The treatment of burn patients injured in combat underwent major improvement in World War II by the application of a fluid resuscitation formula developed by a National Research Council Committee chaired by Dr. Isadore Ravdin, the Chairman of Surgery at the University of Pennsylvania and later Commander of the University of Pennsylvania Unit that provided surgical care in the China-Burma-India Theater of Operations.[20] Burn care slowly evolved thereafter, but during the Vietnam conflict it was materially advanced by the use of treatment techniques developed and applied at the U.S. Army Institute of Surgical Research (the Army Burn Center) beginning in 1947. In January of 1968, effective topical antimicrobial chemotherapy, developed at that institute, was first applied to combat casualties in Vietnam. Topical antimicrobial chemotherapy and other therapeutic innovations for the treatment of burn patients, widely adapted in the civilian community, have significantly improved the outcomes and reduced the mortality of severely burned casualties.[1]

TABLE 2 Advances in Combat Casualty Care: 1914–2007

I. WORLD WAR I
- A. Use of intravenous fluids and blood transfusions
- B. Motorized ambulances
- C. Laparotomy for penetrating abdominal wounds
- D. Use of surgical specialists
- E. Effective topical antisepsis: Carrel-Dakins wound irrigation system
- F. Antitetanus serum
- G. Radiologic localization of foreign bodies
- H. Neurosurgical trauma databank

II. WORLD WAR II
- A. General availability of whole blood and plasma
- B. Formulaic resuscitation of burn patients
- C. Availability of "well trained" surgeons and use of specialty-specific Auxiliary Surgical Groups
- D. Hierarchical organization of trauma care
- E. Use of antibiotics
- F. Use of fixed wing aeromedical evacuation
- G. Identification of "Wet Lung in War Casualties"

III. KOREAN CONFLICT
- A. Fluid resuscitation adequate to correct shock and prevent organ failure
- B. Availability of board certified surgical specialists
- C. Forward availability of definitive surgery
- D. Use of helicopters for patient transport
- E. Primary repair and vascular grafts for injured vessels
- F. Use of hemodialysis in theater of operations
- G. Identification of high output renal failure

IV. VIETNAM CONFLICT
- A. General use of helicopters for patient transport
- B. Monitoring of organ function in theater of operations
  - 1. Blood gas measurements
  - 2. Serum chemistries
- C. Portable radiology equipment
- D. Use of mechanical ventilators in theater of operations
- E. Effective topical antimicrobial chemotherapy for burns
- F. Staged intercontinental aeromedical transport of burn patients
- G. Identification of Acute Respiratory Distress Syndrome

V. OPERATION DESERT SHIELD/STORM
- A. Burn team augmentation of evacuation hospitals to provide theater-wide burn care
- B. Reactivation of intercontinental burn patient transport system

VI. OPERATION ENDURING FREEDOM AND OPERATION IRAQI FREEDOM
- A. Development of a military trauma registry
- B. "Low volume" resuscitation fluids – colloids and red blood cells
- C. Hemostatic agents
  - 1. Systemic
  - 2. Topical
- D. Use of "damage control" initial surgery
- E. Use of endovascular stents
- F. Common use of external fixators
- G. Improved tourniquets
- H. CAD/CAM limb prostheses

CONFLICTS SINCE VIETNAM

Integrated clinical/laboratory research within the theater of operations has been lacking in all conflicts since Vietnam. During Operation Desert Storm, burn treatment teams were assigned to three evacuation hospitals in Saudi Arabia to provide theater-wide burn care capability. The staged intercontinental transfer of burn patients from the theater of operations to the Army Burn Center, with experienced burn surgeons attending the severely burned patients as instituted during the Vietnam Conflict, was reactivated for Operation Desert Storm and has been reactivated again for the current conflicts.[1] Additionally, under the direction of Colonel John Holcomb and his staff members at the U.S. Army Institute of Surgical Research, in-theater burn care capability has been provided, as have individuals to supervise research projects focused on field first aid, resuscitation fluid, and coagulation agents, as well as the development of a user-friendly trauma registry.

Over the past 93 years, experience in the care of combat casualties and biomedical research activities by the U. S. military, focused on the problems occurring in combat casualties, have contributed significantly to overall surgical progress (Table 2). Treatment refinements developed during wartime and research findings generated during conflict and the interbellum periods have been transferred to the civilian community to improve the care of all trauma patients.[21] Similarly, technological developments and research findings generated in civilian laboratories have been readily integrated into military trauma care. Advances in wound care include effective topical antimicrobial chemotherapy for burns and other problem wounds, and the use of infection monitoring and surveillance systems to facilitate infection control in the ICU. Refinements of fluid resuscitation have essentially eliminated acute renal failure as a complication in combat casualties and have identified the hazards of excessive resuscitation (which are of considerable current interest). Civilian trauma patients have benefitted by the transfer of prophylactic hemodialysis, the use of high pressure interrupted flow-positive pressure lung-protective ventilation, and the development of full-spectrum metabolic support regimens. The organization and delivery of civilian trauma care has been materially enhanced by adopting and adapting the military use of helicopters for patient transport and the establishment of trauma and burn centers within hierarchical regional trauma systems.

REFERENCES

1. Pruitt BA Jr. Combat casualty care in surgical progress. *Ann Surg.* 2006;243:715–729.
2. Ravitch MM. A Century of Surgery. Vol. 1. Philadelphia. J.B. Lippincott, 1981. 2 (pp. 225).
3. Sparkman JF. The Southern Surgical Association: The First Hundred Years 1887–1987. Philadelphia. Lippincott, 1989.
4. Bamberger PK. The adoption of laparotomy for the treatment of penetrating abdominal wounds in war. *Mil Med.* 1996;161:189–196.
5. Jones DF. The role of the evacuation hospitals and the care of the wounded. *Ann Surg.* 1918;68:127–132.
6. McCaughey BG, Garrick J, Carey LC, et al. Naval support activity hospital, Danang: combat casualty study. *Mil Med.* 1988;153:109–114.
7. Depage A. General considerations as to the treatment of war wounds. *Ann Surg.* 1919;69:575–588.
8. Cushing H. From a Surgeon's Journal 1915–1918. Boston. Little Brown. 1936;50–51.
9. Hanigan WC, King SC. Cold blood and clinical research during World War I. *Mil Med.* 1996;161:392–400.
10. Gibson CL. The Carrel method of treating wounds. *Ann Surg.* 1917; 66:262–279.
11. Cannon WB, Bayliss WM. Muscle Injury in Shock. Medical Research Committee (Great Britain). Special Report Series No. 26 VIII, 1919, pp. 19.
12. Rankin FW. Mission accomplished: the task ahead. *Ann Surg.* 1949; 130:289–309.
13. Brewer LA III. The contributions of the Second Auxillary Surgical Group to military surgery during World War II with special reference to thoracic surgery. *Ann Surg.* 1983;197:318–326.
14. Beecher HK, ed. The Physiologic Effects of Wounds by the Board for the Study of the Severely Wounded. Washington, D.C. Historical Division. Army Medical Library. Office of the Surgeon General. Department of the Army, 1952.
15. Wangensteen OH, Smith J, Wangensteen SD. Some highlights in the history of amputation reflecting lessons in wound healing. *Bulletin History Med.* 1967;41:97–131.
16. Whalen TJ Jr, Burkhalter WE, Gomez A. In, Welch CD, ed. Management of War Wounds: Advances in Surgery, Vol. 3. Chicago: Yearbook, 1969, pp. 350.
17. Teschan PE, Post RS, Smith LH Jr, et al. Post-traumatic renal insufficiency in military casualties: I, clinical characteristics. *Am J Med.* 1955;18:172–186.
18. Rich NM, Collins GJ, Anderson CA, et al. Octagynous venous interposition grafts in repair of major venous injuries. *J Trauma.* 1977;17:512–520.
19. Pruitt BA Jr. Centennial changes in surgical care and research. *Ann Surg.* 2000;232:287–301.
20. Pruitt BA Jr. Multidisciplinary care and research for burn injury: Presidential Address, American Burn Association Meeting. *J Trauma.* 1977;17:263–269.
21. Eastridge BJ, Jenkins D, Flaherty F, Schiller H, Holcomb JB. Trauma system development in a theater of war: experiences from Operation Iraqi Freedom and Operation Enduring Freedom. *J Trauma.* 2006;61:1366–1373.