

Review

Historical review of emergency tourniquet use to stop bleeding

John F. Kragh Jr, Col., M.C., U.S.A., M.D.^{a,*},
Kenneth G. Swan, Col. (ret.), M.C., U.S.A.R., M.D.^b, Dale C. Smith, Ph.D.^c,
Robert L. Mabry, L.T.C., M.C., U.S.A., M.D.^d,
Lorne H. Blackbourne, Col., M.C., U.S.A., M.D.^d

^aOrthopedics, Damage Control Resuscitation, US Army Institute of Surgical Research, MCMR-SRR-R, 3650 Chambers Pass, Building 3610, Fort Sam Houston, TX 78234, USA; ^bDepartment of Surgery, University of Medicine and Dentistry of New Jersey, University Hospital, Newark, NJ, USA; ^cUniformed Services University of the Health Sciences, Professor of Medical History, F. Edward Hébert School of Medicine, Bethesda, MD, USA; ^dUS Army Institute of Surgical Research, Fort Sam Houston, TX, USA

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Abstract

BACKGROUND: Although a common first aid topic, emergency tourniquets to stop bleeding are controversial because there is little experience on which to guide use. Absent an adequate historical analysis, we have researched development of emergency tourniquets from antiquity to the present.

METHODS: We selected sources emphasizing historical development of tourniquets from books and databases such as PubMed.

RESULTS: The history of the emergency tourniquet is long and disjointed, mainly written by hospital surgeons with little accounting, until recently, of the needs of forward medics near the point of injury. Many investigators often are unaware of the breadth of the tourniquet's history and voice opinions based on anecdotal observations.

CONCLUSIONS: Reporting the historical development of tourniquet use allowed us to recognize disparate problems investigators discuss but do not recognize, such as venous tourniquet use. We relate past observations with recent observations for use by subsequent investigators.

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* Corresponding author: Tel.: +1-210-916-3682; fax: +1-210-916-2942.

E-mail address: john.kragh1@us.army.mil

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Tourniquet use, commonly taught in first aid, is based on little experience to guide care and remains controversial.¹ From Alexander the Great's war with Persia to today's war in Afghanistan, tourniquets have been considered alternatively a lifesaver and "an invention of the Evil One."²⁻¹⁶ In contrast to prior poor results, excellent results have been reported recently by users of emergency tourniquets.^{2,17-22} For such a controversial and important topic, one with new developments, the need for an adequate historical report is evident. The objective of this article is to summarize the historical development of emergency tourniquet use from antiquity to the present. We selected sources emphasizing historical development of tourniquets from books and databases such as PubMed (key word: tourniquet), and manual searches provided many references; the search priority was sources with data, clinical summaries, and then notable claims.

Premodern experiences with emergency tourniquet use

A 6th century BC Hindu medical text described tourniquet use in snakebite care.²³ No hemorrhage control was noted. Alexander the Great invaded the Indus River valley and was victorious at the Battle of the Hydaspes in 326 BC. Some Greek troops were bitten by snakes unfamiliar to their physicians, so Hindu physicians were commandeered to treat these soldiers. These physicians introduced tourniquets to the Greeks.⁸ The Hippocratic body of work mentions in passing tight bandaging and distal limb gangrene without noting hemorrhage control, probably because hemorrhage and death, although linked empirically, were not linked philosophically by the ancient Greeks.²³ The philosophical practitioners in the Hippocratic tradition could not relate the death from blood loss to any theory of physiology available to them. The closest they came was the work of an Alexandrian philosopher-practitioner of the 3rd century BC, Erasistratus, who hypothesized that arteries (from the Greek word for air tubes) did not naturally contain blood and when they were injured and bled there were secondary physiological imbalances that might be fatal.²⁴ The secondary inconsistencies associated with the theory limited its acceptance in the century after Erasistratus' proposal, but proponents of the theory remained for 400 years because it provided explanations for some observed phenomena. Tourniquets are not normally thought of as a complex, idea-driven technology, but in fact the proper use of the tourniquet demands fine attention to details that are themselves dependent on understanding physiology and pathophysiology in the wounded patient.^{2,19,20,25} Without the theory, the empiricists did not manage the details, and therefore it is not surprising that tourniquet use does not appear to have been popular in the Greek world.

The Romans inherited Hellenistic traditions and imposed philosophical practices of paternalistic responsibility for dependent care. Eclectic military medical practices slowly

evolved. Because the Roman legions were extremely effective armies, military historians have assumed that they must have had many organizational methods used as in modern effective armies, including a military medical system. There is no compelling evidence of a system of Roman military medicine: no Table of Organization (document listing assets of a military unit including manpower, personnel positions, and key equipment) that made a *medicus* (a Roman doctor) in one legion do the same job in another legion; no technical bulletins imposing a standard of care on practitioners in a system; and no evidence of licensure or credentialing of practitioners; in short, no system. That some practitioners in a surgical setting developed tools to control bleeding is clear from textual accounts, how widespread such experiences were is a matter of guess work. There is archeologic evidence of hospital-like structures on the Roman frontier and tools, which probably were surgical instruments, have been found in them, but the nature, scope, and quantity of practice is a matter of speculation.²⁶ In all the discussions that survived, in all the illustrations of battle and care of soldiers, there is no depiction of an emergency tourniquet in use; all the references that exist are ambiguous and refer to surgeries.

Galen (129–200 AD), at the time the most famous surgeon in Rome, criticized tourniquet use, fearful it would increase blood loss from a wound. The Greeks noticed that arteries and veins were noticeably different in structure, containing blood of different color and pressure. Some Greeks knew "that during phlebotomy a loose tie around the limb made the bleeding stronger while a tight one made it stop,"²⁷ but this knowledge found little use, presumably because of the frequency of problems such as gangrene. The difference between arterial and venous tourniquet use thus was known, but by few. Because the flow of blood was poorly understood by the Greeks, they struggled to use the device as easily as today.²⁸ Today's understanding of Galen's thoughts on tourniquets is most dependent on Guido Majno,²³ a medical scholar, who described Galen's care of casualties such as Roman gladiators. His hemorrhage control techniques were listed in a specific order in attempts to stop bleeding, eventually including vessel ligation. Majno²³ wrote that "Galen, for all his science, failed to appreciate the possibilities of the tourniquet for stopping hemorrhage." Galen thought venous (dark red) and arterial (bright red) blood had separate origins. He thought venous blood originated in the liver and arterial blood in the heart; the blood flowed from those organs to all parts of the body where it was consumed. Majno described Galen's understanding of the tourniquet as follows, "He must have known of its current use in a different context (for cases of snake bite); and he may have heard of its sporadic use against bleeding, as we shall presently see."

I find this failure hard to understand, but one can try to rationalize. First, Galen's crude method of squeezing with fingers may have worked well enough, especially because he did not worry about the wound being infected. Second,

he was preoccupied with the wound itself and did not realize the danger of blood loss as a cause of death, by what is now called hemorrhagic shock. Third, he may have had the wrong mental image of what a tourniquet really does.

I found this wrong mental image forcefully expressed in the homely booklet of Scribonius Largus, presumably written in Rome some 150 years earlier. The passage is precious because it shows how surgeons could reason about bleeding before they had learned about the circulation of blood, it shows how the obvious is entirely dependent on the point of view, and it reveals incidentally that some form of the tourniquet was in use in 1st century Rome, perhaps as a passing fad. Somewhat shortened, the text reads: "One should sponge the wound with water or vinegar and prevent the limb from being constricted [by a tourniquet], which most doctors do, not realizing that by compressing the muscles they force more blood out of the wound . . . In the same way, if you tie a rope around a skin bag and tighten it, if that bag has a leak, it will of course squirt out its contents."²³

Scribonius finds this so exasperatingly obvious that his language lapses into invective. Referring to those doctors who, in his view, are making hemorrhage worse by applying tourniquets, he concludes: "Et, o bone deus, hi sunt ipsi, qui imputant suam cul-pam in medicamentis quasi nihil proficientibus," which translates to "And, good Lord, these are the same physicians who always give the fault to the medicines!"²³

Majno²³ illustrated the skin bag analogy in a figure that showed Scribonius' thinking. Similar to the Greek and Roman experience with phlebotomy, investigators have experienced such increased bleeding with venous tourniquet use.²⁰ This phenomenon has sometimes been called *paradoxical bleeding* because the tourniquet is used to stop bleeding yet it inexplicably soon worsens. Scribonius' empiric observations paralleled his concept of bleeding.²³

The Roman legions imposed some standards of medical practice that vanished by the 5th century. Slowly after the 10th century, a written surgical tradition re-emerged; this intellectual tradition was called *surgeons of the long robe*, whereas the craft tradition was called *surgeons of the short robe*, who frequently went with their fellow townsmen when the community was deployed to war. As this tradition re-emerged, a new one joined it, the *feldsher* or *field barber surgeon*. The mercenary bands of the Renaissance employed them to save lives and money. Charles V of Spain, the Holy Roman Emperor, had *tercios*, Spanish infantrymen of the Renaissance, fight across Europe while accompanied by 50 field surgeons who trained apprentices, had guilds, and, eventually, the new printing press in teaching others.

In 1517, Hans von Gersdorff, a founder of Prussian military medicine, published a trauma surgery atlas and described tourniquet use in amputation surgery.²⁹ In the 16th century, proximal to a planned amputation, barber-surgeon Ambroise Paré recommended tying "a strong or broad fillet like that which women usually bind up their hair withall."²⁵ In 1593, Wilhelm Fabry of Hilden (Fabricius Hildanus), often called the father of German surgery,

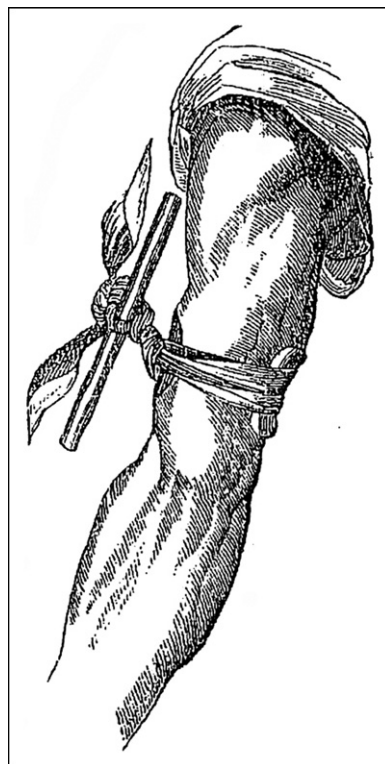


Figure 1 Spanish windlass tourniquet with compression pad.³⁰ Today it is categorized as an improvised tourniquet.

described use of a stick to twist a circumferentially constrictive bandage in amputation surgery. The stick, sometimes called a *Spanish windlass* (Fig. 1), acted as a means to gain mechanical advantage in tightening.³⁰ In the Renaissance, small armed forces had the *feldsher*, who remained near the troops, but as the battlefield and force size grew and as surgical hospitals were developed and deployed, practitioners slowly got farther from the casualty. Eventually, there were simply not enough surgeons to put them close enough to casualties to make a major difference in hemorrhage control.

In 1628, William Harvey, an English physician, was the first Westerner to correctly detail blood circulation pumped by the heart through arteries and returned by veins, which helped to better understand how to stop limb bleeding. In 1674, Étienne J. Morel, a French army surgeon often credited with the first unambiguous claim of battlefield tourniquet use, described a tourniquet used at the siege of Besançon, France.²⁵ The tourniquet included a belt that went through a wood block (with a hole at each end), and a stick was used in the loop of the belt around the limb to twist as a windlass; this was known as a *block tourniquet*. Morel's tourniquet provided a basis for the much improved device of Petit in the early part of the next century.

In 1718, Jean-Louis Petit, then Paris's foremost surgeon, described inventing a screw device (Fig. 2) for which he coined the word *tourniquet* from the French *tourner* (to turn).³¹⁻³³ It required no assistant and could be released readily and reapplied.²⁵ A typical discussion of the device

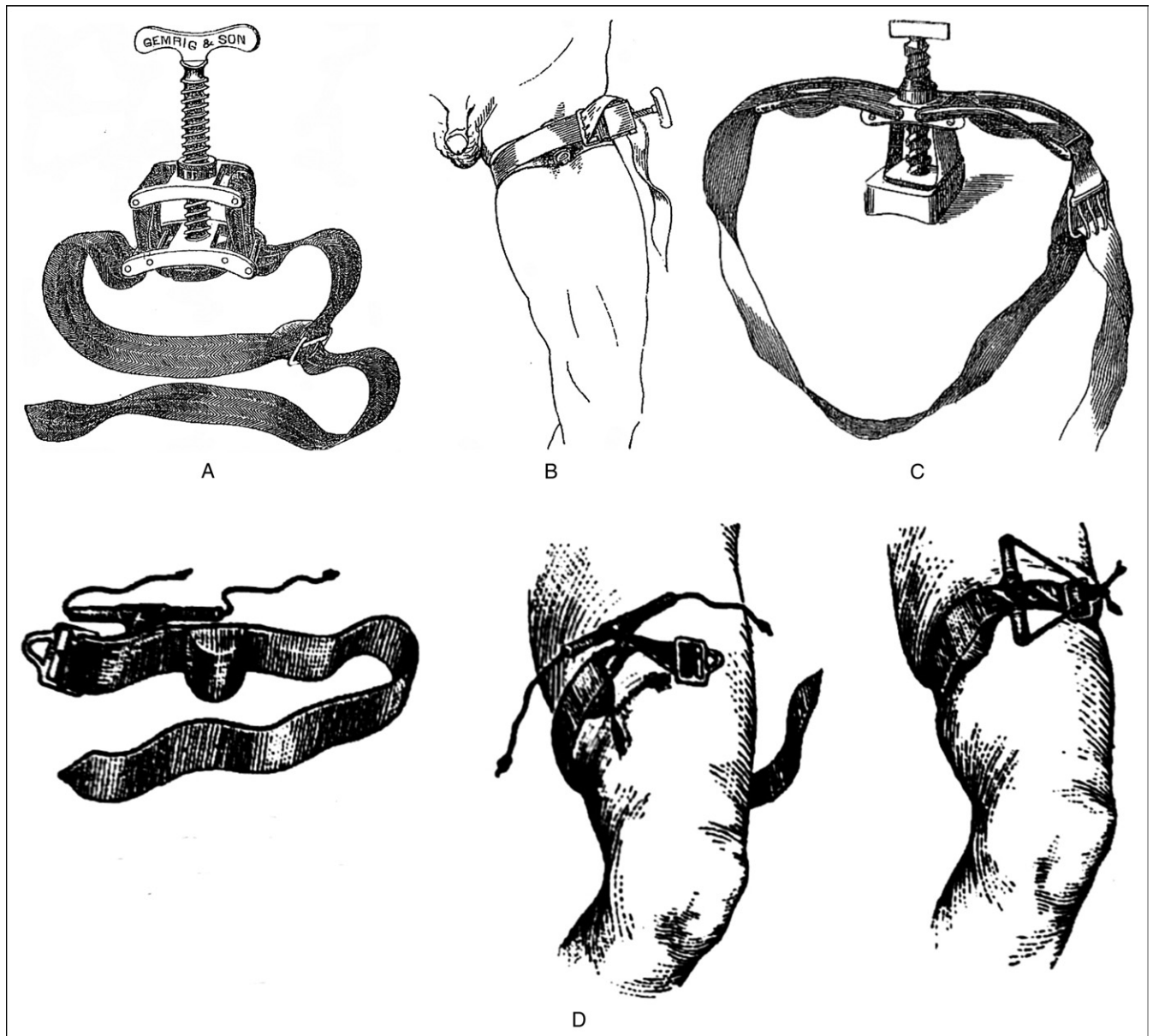


Figure 2 Asymmetric tourniquets. (A) Petit’s screw tourniquet circa 1863.³¹ (B) Petit’s tourniquet with a compression roll over artery.³¹(C) Surgeon-Major Moffitt’s asymmetric winged screw tourniquet.³²(D) Three views of St. John Ambulance tourniquet, which was asymmetric and had a windlass with an attached compression roll.³³

by a user is as follows: “The Tourniquet of Petit. This consists of 3 parts, viz: [sic] the pad to compress the artery—which should be firm narrow and flat; —a strong band to embrace the limb; and a screw by which this band is tightened, and the artery more firmly compressed. The Pad [sic] should be so placed as to compress the artery against the bone; and the screw turned lightly until the first incisions are made, or, what is better still, until hemorrhage from the artery demands some additional assistance for its restraint.”

The advantages of the tourniquet are that it can be used more readily by the ignorant—the patient himself being able to manage it properly; it ensures a more reliable and permanent pressure; it compresses all the branches of the artery as well as the main trunk itself; it never tires, as do the

fingers; it controls hemorrhage as well as in anomalous bifurcations and distributions, as under ordinary circumstances; and it presses upon the nerves and, thus, to some extent, diminishes the sensibility of the part.

The disadvantages of this instrument are that it interferes with the venous circulation; by accumulating blood in the part it causes a great loss of that fluid during the surgery; and it may induce mortification if used ignorantly or too persistently by paralyzing the nerves beneath it to lower the vital energies of the tissues to which they are distributed, and by cutting off the supply of arterial blood.³⁴

Petit’s tourniquet was asymmetric in its application of pressure by design and was intended to compress the arteries preferentially. The tourniquet and its modifications were

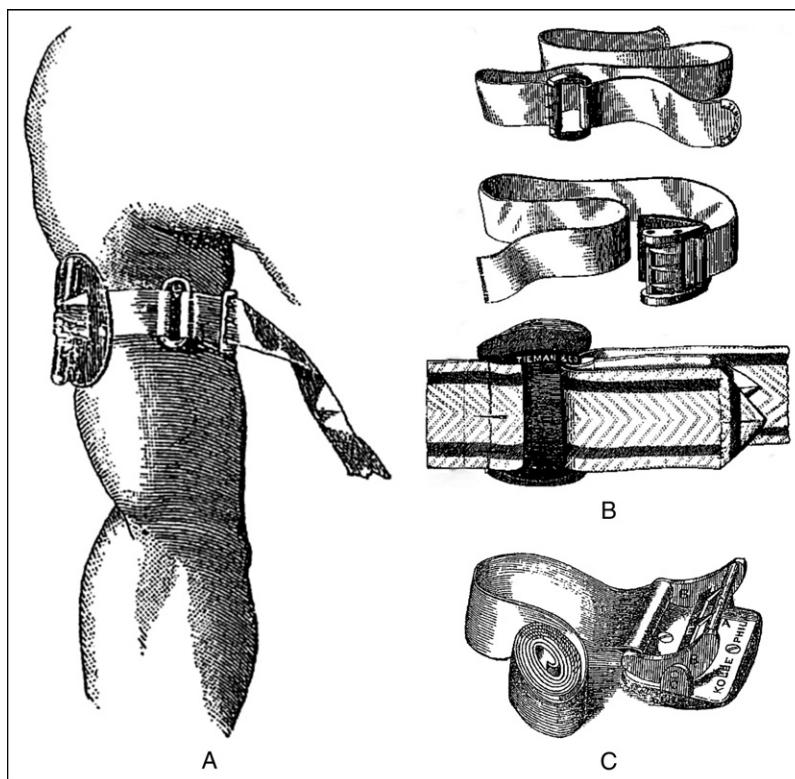


Figure 3 Strap and buckle tourniquets. (A) Field tourniquet.³⁰ (B) Three field tourniquets of the US Civil War.³⁵ The bottom tourniquet was copied from a Prussian model. The US Army tourniquet used in World War II was similar to the bottom model except the buckle was more developed. (C) Strap, buckle, and windlass tourniquet.³⁰

used for more than a century. No evidence indicates that it was used before the hospital to control battlefield hemorrhage or that it was used other than for emergency and elective limb surgery. By Petit's day, military medicine began to emerge from the apprentice and occasional publication models of learning to a more recognizable modern form. The French and the Prussians developed military frontier hospitals where young surgeons were trained in battlefield surgery (Fig. 3).³⁵

In 1786, Sir William Blizard,³⁶ a fellow of the Royal Society, lectured to the Maritime School at Chelsea. He described tourniquet use "in cases of dangerous effusions of blood from wounds, &c." The lecture to students was later published for the general benefit of all. Blizard,³⁶ the school surgeon, prefaced the lecture with a case report of a preventable death from prehospital hemorrhage in Captain Vide Drinkwater's history of the siege of Gibraltar on September 30, 1781, wherein a soldier lost his legs from a cannon shot.

He bore amputation with prodigious firmness, but died, soon after, through loss of blood previously to his being brought to the hospital. This fact was represented to the governor and the sergeants of the different regiments were ordered to attend the hospital to be taught by the surgeons how to apply the tourniquet; which was afterward productive of very beneficial consequences.³⁶

Blizard³⁶ offers a few vignettes similar to this one in a first aid lecture on naval casualty care to midshipmen. For example, he noted that because surgeons worked in the

ship's cockpit and could not "instantaneously render assistance to those in a remote part of the vessel,"³⁶ those aboard ships were to be trained in hemorrhage control measures such as tourniquet use. Blizard³⁶ discussed a version of Morel's block tourniquet, which required a drawing and lengthy explanations on how to use it; he wrote that it was easier to use than to describe its use. That version included a leather band that also had the belt pass through a hole at each end, similar to the block, but the leather band sat underneath the windlass, apparently to avoid twisting the skin. Over the years that he gave the lecture, Blizard noted the following:

"I requested the sentiments of an intelligent naval surgeon on the subject. I can best express my opinion by relating to you the practice of an ingenious surgeon in the service, and assuring you that his and my sentiments perfectly coincide. — Mr. XXX, surgeon of the BARFLEUR (the name of the British warship), had observed, with great concern, the dreadful effects of wounds that happened in time of action, from the seamen being entirely ignorant of the manner of applying the tourniquet, many instances having occurred of men bleeding to death, particularly in the tops, before assistance could possibly be rendered them." —To prevent these evils, as much as was in his power, he provided every seaman, stationed in the tops, with a tourniquet; and, on every opportunity, taught them the method of applying it; so that, in a short time, they became perfectly expert in its use."³⁶

Blizard³⁶ pointed out that 2-boned limb segments cannot be compressed sufficiently to occlude the artery between the bones, a misconception that may be more related to the poor designs of his era such as narrow or asymmetric tourniquets. Blizard³⁶ also pointed out that a little medical knowledge was a dangerous thing and that misuse was problematic. He recommended that a Petit-type screw device be fielded to each ship (soon implemented) and that every family should have a block tourniquet at hand.³⁶

In the Crimean War, George H. B. Macleod, a British surgeon at a civilian hospital, noted that few casualties presented alive with major vascular injuries, that many others likely died of hemorrhage before treatment, and that, “in that era, patients who survived long enough to be treated likely did not need a tourniquet.”³⁷ Macleod noted the following:

It has been the experience of most wars, certainly of the late one, that tourniquets are of little use on the battle-field; for though it is unquestionable that a large number of the dead sink from haemorrhage, still, it would be impossible, amidst the turmoil and danger of the fight, to rescue them in time, the nature of the wounds in most of these cases causing death very rapidly. A great artery is shot through, and in a moment the heart has emptied itself by the wound. It would be an experiment of some danger, but of much interest, as bearing on this question, to examine the bodies of the slain immediately after a battle, and carefully record the apparent cause of death in each case.³⁷

Macleod³⁷ mentions the tourniquet a few more times in his text and noted that it was effective on the thigh less often than elsewhere.³⁷ He does not explain why effectiveness varied by limb segment, but today it is known that girth is associated inversely with effectiveness. The tourniquet was blamed disproportionately compared with poor medical planning, lack of casualty care training of the troops, and marginal medical logistics.²⁸ The evacuation times from the point of injury to surgical care were usually much longer than currently, and the duration of ischemia led to high complication rates. However, Macleod³⁷ contemplates, similar to Blizard,³⁶ the concept of preventable deaths on the battlefield. What is considered preventable varied over the centuries, and recent data have not resolved the disagreement fully. Different armies, in different wars, would tackle the problem differently throughout the 19th century.

In 1861, the American Civil War's first year, Confederate J. Julian Chisholm³⁸ noted poor tourniquet results in a war surgery manual. He noted that troops too often used tourniquets needlessly. Chisholm's Union counterpart, Samuel D. Gross,³⁹ an academic surgeon, published concurrently and noted that “every one may put into his pocket a stick of wood, six inches long, and a handkerchief or piece of roller, with a thick compress, and be advised how, where, and when they are to be used.” The most famous casualty in need of a tourniquet was a Confederate commander, Albert Sidney Johnston, who died of a gunshot wound while riding his horse, Fire-eater, at the battle of Shiloh in 1862. He had

massive hemorrhage from a partial transection of the popliteal artery, yet an unused tourniquet was in his pocket. Johnston's army medical director had issued tourniquets to staff officers and examined the body the night of the injury. He held that had the tourniquet been used, Johnston could have been saved.⁴⁰ Johnston was shot previously in that limb and had persistent numbness, which may have contributed to the delay between injury and wound detection. The doctor was a long way from the place of wounding, and the problem of being killed from bleeding did not come to the doctor's attention as being different from other soldiers killed in action. Arguments among surgeons were heated because the absence of evidence permitted any opinion to withstand counterargument.

In 1864, Joseph Lister, a scientific English surgeon, reported tourniquet use to create a bloodless surgical field for excision of a tuberculous wrist to preserve the hand without the excessive blood loss typical of that procedure.²⁵ In 1873, after the Franco-Prussian War, Johannes Friedrich August von Esmarch, Germany's prominent military surgeon, reported on a bandage wrapped around the limb that exsanguinated veins, occluded arteries, and controlled bleeding; a similar first aid device was issued to individual soldiers and used in the wars of 1869–1870 (Fig. 4).^{30,33,35,41} Esmarch altered the India rubber emptying bandage of Grandesso-Sylvestri by using woven rubber and tubing, and there have been many subsequent variations of Esmarch's development.⁴ He called this device a *bandage*, not a *tourniquet*, yet it could be used purposefully to stop both bleeding and pulse. Users were not taught to exsanguinate limb veins as was performed routinely in surgery.⁴¹ Esmarch reported that “very often in transporting a patient the best applied tourniquet or compress may shift a little: it then does more harm than good.”⁴¹ Esmarch also invented a dressing as a triangular linen or muslin cloth that can be used to improvise a field tourniquet. Esmarch noted that in first aid a tourniquet could be wrapped one layer atop another, tightly and repeatedly, until the pressure underneath increased enough to stop the bleeding; he also recommended watering the fixed bandage so that it would shrink on drying to increase pressure.⁴¹ In 1881, Richard von Volkmann, a German orthopedic surgeon, noted paralysis after use of Esmarch tourniquets; if wrapped too tightly, high pressures with Esmarch's tourniquet risked nerve palsy.²⁵

20th and 21st century experiences with emergency tourniquet use

In 1904, Harvey Cushing developed a pneumatic tourniquet from the Riva-Rocca sphygmomanometer that compressed underlying tissue and vessels with pressurized air in a cuff-like bladder. Pneumatic tourniquets more evenly distributed pressures over wider areas than previous tourniquets and were monitored more easily for safety. They were superior to Esmarch's tourniquet because they could be

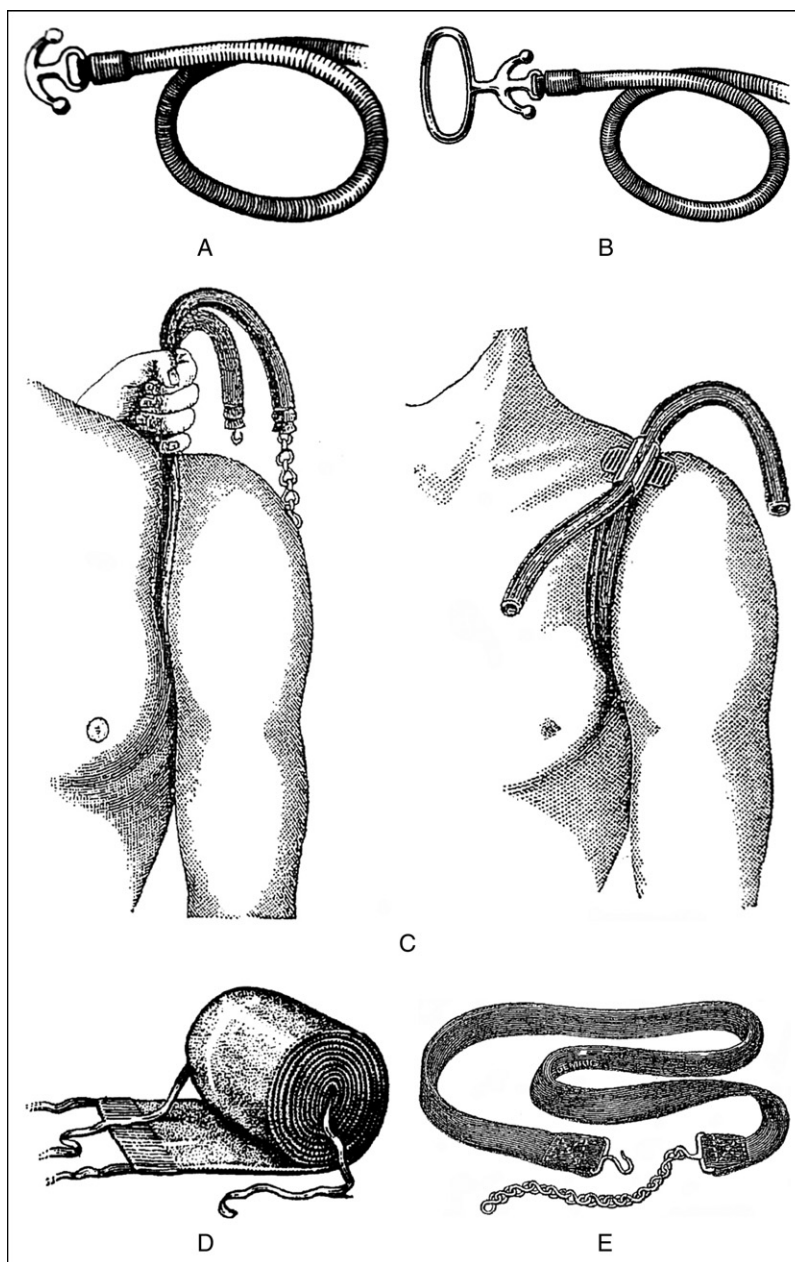


Figure 4 (A–E) Rubber tourniquets.³⁷ (A) Samway's rubber tube tourniquet with hooks.³³ (B) Callander's modification of Samway's tourniquet with handle.³³ (C) Two views of a rubber tube tourniquet before shoulder disarticulation.³⁵ (D) Esmarch's bandage, which could be used as a first aid tourniquet.³³ (E) Esmarch's rubber tourniquet with chain and hook.³⁰

applied and removed quickly while decreasing the risk of nerve palsy.²⁵

In 1916, during World War I, Major Blackwood⁸ (first name unreported), of the Royal Army Medical Corps, stressed the importance of controlling hemorrhage in casualty care. However, he was “inclined to think that tourniquets are an invention of the Evil One, and it is no exaggeration to say that many limbs have been lost during this campaign by the indiscriminate use of them. We do not mean to say that, if a man is shot in the femoral or other large vessel, a tourniquet is not required, though here the majority of cases would be dead before a tourniquet could be found and applied.”⁸

World War I introduced the battlefield medic. The French had introduced litter bearers before, and the British had begun to use the regimental bandsmen as litter bearers, but they were not usually present at the height of the battle. In World War I, the US Navy began to transfer corpsmen from the ambulance evacuation companies to the forward units of the US Marine Corps regiments serving with the Allied Expeditionary Force at the height of battle. Corpsmen with the Marines had attended a paraprofessional school, being taught some medical science and advanced first aid, they carried a new pressure dressing developed by the Navy for use until aid could arrive, but there is no record of their being issued tourniquets.⁴² In an emergency tour-

niquet review that described World War I tourniquet use, a British manual was criticized as shortsighted in its denunciation of tourniquets.²⁸

A contemporary of the British military surgeons on the opposing Central Powers was Lorenz Bohler (1885–1973), an Austrian trauma surgeon, who was a division surgeon and who later was a leader in large casualty hospitals during both World Wars. Bohler, considered the creator of modern accident surgery, also had experience with tourniquet use, but he relayed the lessons learned in more detail than Blackwood.⁴³ More detail was added by his son, Jorg.^{44,46} These lessons have not been seen referenced by prior investigators of emergency tourniquet use, but by the time Lorenz Bohler published, German surgery was less widely studied by English-speaking professionals and the issue of tourniquet use had largely been settled by first aid authorities. Lorenz Bohler relayed summary lessons from emergency casualty care that was both prehospital and hospital. He offered guidelines for “circumstances predisposing to failure in first aid and at the clearing station”: (1) neglecting rapid arrest of hemorrhage by elevation and the application of compression bandages; (2) failure to apply a clamp or tourniquet when hemorrhage is not arrested by compression; (3) unnecessary application of a tourniquet, which may lead to ischemic disturbances, necrosis of the extremity, or to septicemia, if it remains in place more than 3 hours; and (4) deficient (that is, loose) application of the tourniquet, which may cause congestion and increase hemorrhage.⁴³

Bohler⁴³ went on to note that “death, therefore, may occur in a few minutes if counter-measures [pressure or tourniquet] are not immediately applied.” He listed the observed risks of tourniquets being too loose (increased bleeding) or too tight (nerve palsy). He described several types of tourniquets he had seen used with specific problems and precautions for optimal use. He described problems with prolonged use, delayed transportation, and delayed release of the tourniquet. Bohler⁴³ did not mention care under fire and simply reported what he saw near the end of the casualty evacuation chain, mostly at a specialty care hospital. Bohler⁴³ related the outcome of a policy change he recommended:

In both World Wars, I saw many limbs needlessly constricted, which were frozen during transport because of use of the tourniquet, and which had to be amputated. The original injury itself had been relatively minor and certainly would not have caused fatal hemorrhage. At the beginning of World War I, many soldiers carried rubber bandages to the battlefield. When in 1914, the number of amputations necessary because of the improper application of tourniquets increased rapidly, I suggested to the Commanding Medical Officer that this practice should be discontinued. The injurious effects of improperly applied tourniquets then disappeared.⁴³

Bohler⁴³ did not detail when the policy change occurred, did not mention specific training or doctrine, and did not say

why the problems recurred in World War II. He described in detail how to and how not to use tourniquets. He indicated there are times when to and when not to use them. He related several aspects of proper tourniquet use and misuse associated with specific sequelae and outcomes. Bohler⁴³ noted a policy change whose recommendations were based on evidence, and he implied that the training and doctrine for applicators were inadequate. The trials and errors on the German side appear to be similar to those of the Allies; however, the depth and breadth of Bohler’s report was greater than any allied report of that era.⁴³ It is unclear whether the rubber bandage Bohler referred to was derived from Esmarch’s bandage. Bohler’s work was pivotal as the thinking changed from whether or not to use the tourniquet to how and when it should be used.

From his experience serving in the Spanish Republican Army during the Spanish Civil War in the 1930s, New Zealander Douglas W. Jolly⁴⁵ wrote that “more limbs and lives are lost at the front from the improper use of the tourniquet than are saved by its proper use.” He stressed tourniquets in use be detected by providers of emergency care because tourniquets could be covered and unseen under splints, clothing, or blankets. Jolly,⁴⁵ an experienced field surgeon, observed that both improper and proper use of the tourniquet occurred, but he gave no supporting data and provided no further description. Although Jolly’s⁴⁵ comments implied wide use of tourniquets occurred, he plainly intended to discourage such use.

In 1936, Reginald Watson-Jones⁴⁶ began a popular British instructional course on orthopedic casualty care. Later, he became a member of the United Kingdom’s War Wounds Committee of the Medical Research Council that studied hospitalized survivors during World War II. He was the senior orthopedic consultant to the Royal Air Force at Headley Court, a rearward hospital near London, and was later knighted for his development of effective rehabilitation services. An influential author (his fracture textbook had 15 editions from 1940 to 1985), he abolished first aid tourniquets as he witnessed their misuse and resultant morbidity. In his textbook, Sir Reginald Watson-Jones⁴⁷ distilled Jolly’s⁴⁵ comments into the statement, “More limbs have been lost by the use of tourniquets than have been saved.” However, he gave anecdotal data and little explanation besides a morbid case report from surgical, not emergency, use.⁴⁸ As an influential journal editor, he further turned his little-evidenced comment to, “More lives have been lost than were ever saved by the use of the tourniquet.”⁴⁹ Watson-Jones concluded that the emergency tourniquet was a dangerous weapon. His tourniquet teaching had little supporting evidence, yet tourniquets were banned for decades.

In the Italian campaign of the Army in World War II, Wolff and Adkins⁵⁰ reported their experience with emergency tourniquet use in 200 cases, but no data were reported—just lessons learned and 3 vignettes. Wolff and Adkins⁵⁰ noted that the US Army strap and buckle tourniquet lost tension during application, and it was often inef-

fective on thighs.^{50,51} The US Army tourniquet then was a standard-issue, 1.5-inch wide, 42-inch long, cotton webbing strap of nonpneumatic design, including a spring-tension clamp buckle with teeth. It did not have a windlass or other mechanical advantage. It was ineffective in controlling arterial bleeding because later testing showed that it could not reliably eliminate the arterial pulse in the thigh and that it may have contributed to the widespread feeling that tourniquets were ineffective.⁵¹⁻⁵⁶

In the Korean War, several reports of tourniquet use were favorable, and the data and lessons reported were in accord with the World War II report of Wolff and Adkins.⁵⁰ Again, these reports were not as comprehensive as Lorenz Bohler's experience.^{43,56-59} The World War II era tourniquet still was used and again was found to be ineffective all too often. In 1954, Lieutenant Colonel Carl W. Hughes, a surgeon based at Tripler Army Medical Center, reported his Korean War experience: "a study of 79 major vascular injuries in extremities showed that 47 percent were admitted with a tourniquet in place which had been applied from 40 minutes to 14.5 hours previously, the average time being 4 hours."⁵⁷ Hughes did not give specific outcomes but gave a general discussion of tourniquets and later noted the difficulty that tourniquet users had in differentiating arterial from venous bleeding.⁵³

One of the specific surgical studies of severely wounded casualties from the Korean War dealt directly with hemorrhage control but only indirectly with tourniquets.⁵⁹ Citing data in detail, Artz et al⁵⁹ reported that hemorrhage control saved lives and uncontrolled hemorrhage led to death; even with a bias of studying those survivors who arrived at a hospital, they measured fewer transfusion requirements in those casualties that had hemorrhage control. They emphasized that limb wounds can bleed massively and thus be lethal. They reported that tourniquet use can control limb hemorrhage while blood replacement therapy is ongoing. This pivotal study promised improved trauma care by evidencing hemorrhage control benefits with tourniquet use; rarely had hemorrhage control been evidenced to be lifesaving.

In the Vietnam War, most US Army reports contained limited tourniquet data, but analyses led to an estimated rate of deaths from limb hemorrhage potentially amenable to tourniquet use at 7% among US casualties.^{60,61} Similarly, in a 1970 analysis of casualties killed in action in Vietnam, one surgeon recorded data indicating that approximately 7.4% or 2,590 lives could be saved with better prehospital care namely tourniquets.⁶³ Interestingly, a brief analysis of preventable deaths in the 1905 Russo-Japanese War came to a similar conclusion.⁶⁴ A study of 98 US casualty fatalities from exsanguination in Vietnam noted that nearly 19% had injuries suitable for control by a tourniquet or appropriately applied direct pressure.⁶¹

The Israeli Defense Forces adopted a policy in 1987 encouraging emergency tourniquet use with specific consideration of care under fire wherein the rescuer could use the tourniquet as first aid before seeking cover from gunfire.¹⁷

In 2003, in the largest and most detailed tourniquet study to that date, Lakstein et al reported the Israeli experience from 1997 to 2001; 91 casualties had tourniquets applied prehospital. The investigators reported only Israeli soldiers as casualties, and the results generally were favorable. No deaths occurred, and only 5.5% had nerve palsy; but Husum et al³ criticized Lakstein et al for not being able to show a survival or any other benefit because there was no comparison group.

In the 1989 Operation Just Cause, Navy Sea, Air, and Land (Seal) forces assaulted Punta Paitilla Airfield near Panama City, Panama, and analyzed casualty care.⁶⁵ The study documented that casualties occurred while caring for other casualties while under fire. They noted that "exsanguinating external hemorrhage, particularly from the extremities, is the wound type most likely to benefit from early intervention, . . . rapid control of external exsanguination was the technique most likely to prevent death," and tourniquets saved 2 lives with no sequelae.^{64,65}

Operation Desert Storm in 1991 was so brief that there were little time and data to refine casualty care; however, evidence indicated that uncontrolled limb hemorrhage remained a preventable cause of death.⁶⁶ Of only 3 deaths that occurred in US Corps hospitals from wounds received in action, all had hemorrhage from limb injuries contributing to the cause of death.⁶⁶

In 1993, at Mogadishu, Somalia, Robert Mabry, a US Army special operations forces medic, and his colleagues later reported in 2000 the survival rate of battle casualties incurred with and without tourniquet use; they recommended more tourniquet use on the battlefield.⁶⁷ Prehospital combat casualty care then was categorized as "care under fire" and "tactical field care"; the difference was based on whether gunfire was endangering the casualty and the rescuer. The World War II era US Army tourniquet described by Wolff and Adkins⁵⁰ was still standard, but special units often acquired novel devices or made improvised tourniquets. Mabry et al⁶⁷ noted that 7% of fatalities resulted from penetrating extremity trauma and that hemorrhage control was a vital imperative, especially prehospital, echoing the findings of Bellamy and Maughon from Vietnam.^{62,63}

From 1993 to the present, Captain Frank Butler,⁵²⁻⁵⁴ a Navy ophthalmologist, and others in special operations forces (eg, John Holcomb, Robert Miller, and Robert Mabry), stewarded an effort to systematically assess the needs of tactical combat casualty care.⁶⁸ Acting on the findings of Wolff and Adkins⁵⁰ and Mabry et al,⁶⁷ they recommended testing tourniquets to find the best design available.⁶⁸ Given the Mogadishu experience, application of civilian models of prehospital medical care were not realistic during care under fire.⁶⁵⁻⁶⁷ Prehospital care theory, as in civilian settings, and empiric military results in Panama and Mogadishu were mismatched with lethal consequences. This mismatch led to a clear divergence of civilian and military medical care principles during care under fire.

In 2003, tourniquet designs were screened and tested for Operation Iraqi Freedom.⁶⁸ Army Surgeon General Kevin

Kiley realized that waiting for all information to be in was a recipe for inaction and recommended the Combat Application Tourniquet (CAT; North American Rescue, Greer, SC) as standard issue to deploying US servicepersons.⁶⁸ In 2004, Alec Beekley, a general surgeon, began a study at the emergency department of the coalition's combat support hospital in Baghdad. Beekley et al¹⁸ reported in 2008 that prehospital tourniquet use was associated with better hemorrhage control rates, particularly in the more severely injured casualties: "Fifty-seven percent of the deaths might have been prevented by earlier tourniquet use. There were no early adverse outcomes related to tourniquet use." At the same study site that Beekley et al¹⁸ used, Kragh et al^{2,20} reported a 2006 study of different casualties with mild, temporary, and infrequent morbidity with tourniquet use in a large cohort. Bad experience delimited proper use so the evidence yielded practical guidelines, such as well-designed and tested devices performing best and improved effectiveness of tourniquet use side-by-side if one was not effective.²⁰ The survival rates were higher with prehospital use versus hospital use (89% vs 78%), higher with use before shock onset versus after shock onset (96% vs 4%), and higher with tourniquet use versus without tourniquet use (87% vs 0%).² The latter 2 associations were strong whereas the first was weak so the survival mechanism was evidenced to be by prevention of shock onset; in other words, the evidence indicated tourniquets were a hemorrhage control device, an adjunct in damage control. Differential survival rates based on how and when the tourniquets were used filled the most controversial knowledge gaps and offered the first modern, high-quality dataset indicating that, in war casualties within a comprehensive trauma system, the survival rate was higher with tourniquet use than without. By reconciling disparate data, these studies showed that the right tourniquets used at the right time in the right way for the right casualties saved lives; thus, the question was not whether tourniquets were tools or weapons, but how and when they should be used? With this new knowledge, by 2008 tourniquets were no longer the most controversial item in combat casualty care; they became a rare prehospital intervention evidenced strongly to be life-saving for limb-injured casualties.¹⁶ These developments stimulated recent reconsideration of a selective role for tourniquets in civilian trauma.⁶⁹⁻⁷¹

Conclusions

Although presented chronologically, the long history of emergency tourniquets is tortuous with false starts and false passages mainly written by surgeons, as the Rangers say, "in the rear with the gear," while forward medics faced the immediate task of controlling hemorrhage at the point of injury. Most of the history is without data, but today data support their use—a rare prehospital intervention evidenced strongly to be life-saving. We detailed the historical devel-

opment of tourniquet use so the reader can focus further reading on specific historical aspects of tourniquets and avoid pitfalls, the most dangerous of which remains the tendency to apply civilian experience in a combat situation.

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