STOPPING THE BLEED

How Army surgeons brought tourniquets back into the medical mainstream

Abstract

Tourniquets are an ancient technology, but were long believed to cause nerve damage and gangrene, leading military and civilian medics to avoid using them. Now, researchers at the US Army Institute of Surgical Research are conducting groundbreaking research showing how to use tourniquets safely and effectively, and developing commercial tourniquets that can stop not just bleeding from extremity injuries, but also from previously untreatable pelvis, shoulder, and even neck wounds. That's led to a sea-change in military trauma care: all soldiers are now routinely issued tourniquets, saving an estimated 2,000 lives since the start of the war on terror. The devices are also being widely adopted by civilian first responders, saving thousands more lives across the US.

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Prepared for BEST by
THE CENTER FOR HOMELAND SECURITY AND RESILIENCE

Submission Date
February 5, 2018

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At 1 a.m. on a clear winter night in 2015, Houston police officer Logan Leathers and his partner, Mauricio Peña, were heading outbound on the Katy Freeway on Houston's west side, when they pulled up to a line of stationary vehicles. A driver in a black pickup waved them through, warning of an accident up ahead, Leathers says.

As Leathers and Peña moved through the traffic, they saw a grey Honda Civic lying on its roof, its side caved in; nearby, its driver, a young man in his 20s, sat — conscious, but clearly in shock — dazing at his left leg. His thigh and knee were moving normally, Leathers says, but his foot lay motionless, bent at an obscene angle, while a pool of dark blood spread slowly across the asphalt. The man's lower leg had been all but severed, crushed under his own car as he was flung from the rolling vehicle.

While Peña checked for other casualties, Leathers says he ran to the man, trying to speak soothingly while he reached into his side pocket for a tourniquet. The man's leg was too badly mangled for Leathers to slip the tourniquet over his foot, so he unbuckled the nylon and fabric strap, cinched it back around the man's leg, and used a built-in plastic windlass to twist the loop tighter and tighter. The inch and a half-wide band of fabric bit into the man's leg, collapsing his veins and arteries, and turning off the flowing blood like a creaky faucet.

"I applied the tourniquet above his calf, as hard as I could, and just left it there," Leathers says. "It had bled already — a *lot* — but luckily we got there right as it happened, and the tourniquet was able to stop the bleeding."

Paramedics soon arrived on the scene, and the injured driver was rushed to hospital, while Leathers says he and Peña made themselves busy clearing the freeway. Later, Leathers stopped by the hospital, he says, and learned that the man had survived, and — apart from losing his foot — would make a full recovery.

"The doctor told me every blood vessel and artery was severed. There was just a little skin holding his leg together," Leathers says. "If we hadn't gotten there when we did, he'd have bled to death."

Leathers earned a commendation for his prompt action out on the freeway. "It wouldn't have happened if I hadn't had the tourniquet," he says.

It was only later that the full impact of the doctor's words sank in, Leathers says. He hadn't been taught to use tourniquets while passing through the Houston police academy in 2012; it was only a year later, after a shift in HPD policy, that he and his fellow officers underwent retraining, and were issued tourniquets as part of their standard equipment, he says.

The tourniquet that Officer Leathers was carrying was a commercially made Combat Application Tourniquet (CAT), identical to those now carried by every American soldier.

Tourniquets Reconsidered

The care provided by medics, corpsmen, and pararescuemen on the battlefield is critically important to the survival of U.S. military service members. Approximately 90 percent of combat fatalities occur before the casualty reaches a fixed medical facility, and approximately 25 percent of prehospital combat deaths are potentially preventable, underscoring the critical importance of battlefield trauma care.

Despite this fact, prehospital trauma care changed very little between the American Civil War and the early 1990s. In Vietnam, an estimated 3,400 U.S. service members died from uncontrolled extremity hemorrhage. These warriors could have been saved with a very simple tourniquet. As recently as 1992, first responders in civilian EMS and the military were still erroneously being taught that tourniquet use is dangerous and would likely result in the loss of the extremity.

Recognizing the needless loss of lives on the battlefield, the Navy SEAL community established a flag-level requirement for a comprehensive review of battlefield trauma care. This resulted in a four-year research effort that involved Navy SEAL personnel, other special operations medical providers and faculty members at the Uniformed Services University of the Health Sciences.

The nature of the battlefield environment was considered, as were the training, equipment, and experience of combat medics. Extensive input was also obtained from combat-experienced medical personnel.

The research goal was to prevent as many deaths in the prehospital setting as possible and resulted in the publication of the first Tactical Combat Casualty Care (TCCC) paper in 1996. TCCC called for the aggressive use of extremity tourniquets, a dramatic departure from the prevailing standards of prehospital trauma care.

Getting Tourniquets to the Battle Zone

When American troops first deployed to Afghanistan in 2001, the CAT hadn’t yet been invented, and soldiers weren’t routinely issued tourniquets; instead, they were instructed to simply improvise using bandanas, sticks, or whatever they could find lying around. Even in larger first aid kits, medics had access only to ineffective World War II-era tourniquets that used a strap-and-buckle design, rather than the more powerful and reliable windlass-based CAT device.

The introduction of tourniquets on the battlefield was a result of three specific actions, led by the U.S. Special Operations Command and the U.S. Army Institute of Surgical Research (USAISR). First**,** Col. John Holcomb, at the time the Commander of the U.S. Army Institute of Surgical Research (USAISR) and the Trauma Consultant for the Army Surgeon General, led a team from the U.S. Special Operations Command (USSOCOM), USAISR, and the Armed Forces Medical Examiners System that conducted a review of preventable deaths in Special Operations forces.

Then, USAISR researchers conducted a comprehensive evaluation of commercially available tourniquets to determine which ones were effective at stopping arterial blood flow.

And the third step was challenge was to field the most combat-suitable tourniquet as quickly as possible, an effort sponsored by USSOCOM and executed by USAISR under the leadership of Holcomb and SFC Dominic Greydanus, a Special Forces 18-D medic.

The TCCC Transition Initiative was conducted in 2005 and 2006, and was directly responsible for equipping all deploying Special Operations units with tourniquets.

Now, thanks to the efforts of researchers at the U.S. Army Institute of Surgical Research (USAISR), a new generation of tourniquets — including the CAT, but also next-generation gadgets capable of swiftly stopping bleeding from groin, shoulder, and even neck wounds — has been developed and fielded by the military, and are increasingly also being used by civilian first responders across the country.

New Generation of Tourniquet

The technology itself is deceptively simple — a tough nylon band an inch or so across, a plastic or metal rod with which to twist it tight, and a Velcro loop to keep it from loosening — but it represents a quantum leap in trauma care.

The speed with which modern tourniquets have been embraced by military medics and civilian first responders is remarkable, and a testament to the USAISR researchers who drove the shift, says Dr. John Holcomb, a 23-year Army veteran who commanded USAISR between 2002 and 2008, and who now heads the trauma unit at Houston's Memorial Hermann Hospital.

"In my lifetime in trauma care, I've never seen anything like it," Holcomb says.

No one has done more to bring tourniquets into the medical mainstream than Dr. John Kragh. A clean-cut, grey-eyed former Ranger, Kragh's work with USAISR is credited with definitively establishing both the safety and the utility of tourniquets, and driving policy changes that have saved up to 2,000 soldiers' lives since the start of the war on terror.[1]

"There aren't many studies that have had an impact equal to Dr. Kragh's in terms of saving lives," says Frank Butler, a former Navy SEAL who chairs the Committee on Tactical Combat Casualty Care (CoTCCC), a component of the Joint Trauma System, which was founded at the USAISR and located there for over a decade. "He was laser-focused on the tourniquet question in Ibn Sina, and the military and our nation as a whole has benefited greatly from his work."

Combat Impact

In every major war for which statistics are available, about 8 percent of combat deaths can be traced back to extremity injuries. That was the case in the early years of the war on terror, too,

[1] "Battlefield trauma care then and now: A decade of Tactical Combat Casualty Care" -- p S397

when U.S. soldiers headed to Iraq and Afghanistan with little or no protection against gushing arm and leg wounds.[2]

Thanks to Kragh's research, that has changed: the increased availability of tourniquets means that deaths from extremity injuries now account for less than 1 percent of battlefield fatalities.[3] It's hard to grasp, just from the numbers, how important that is, Butler says.

"Don't look at them as casualty statistics," Butler says. "Imagine lining up a hundred U.S. service members, and having them be fatalities, and realize that with a simple device you could save seven of those people. It's overwhelming to realize the positive impact."

That kind of impact isn't unusual for USAISR, which was created in 1943 as the Surgical Research Unit, based out of a Staten Island hospital. It was tasked with investigating a then-revolutionary new trauma management tool: penicillin. In 1947, USAISR and its 12 employees relocated to the Brooke Army Medical Center, at Fort Sam Houston in Texas. Since then, it has continued to adapt to serve the shifting needs of the warfighter.

One program, originally intended to help treat thermal injuries from nuclear blasts, has evolved into the nation's premier military burn unit, treating soldiers injured by improved explosive device blasts or other modern battlefield episodes. Elsewhere in USAISR's modern offices, the institute's researchers — who now number more than 700 — are investigating everything from regenerative treatments for spinal injuries, to so-called "vampire" medevac missions in which patients receive massive blood transfusions while in-flight.[4]

It's USAISR's focus on trauma, though, that really stands out, says Col. Todd Rasmussen, who served as USAISR's deputy director between 2010 and 2013. The civilian research establishment spends very little on trauma research, so it falls to the military to push things forwards, Rasmussen says.

"The Institute of Surgical Research plays an absolutely critical role. It's the sustaining pilot light of combat casualty care research for the country," he says. "And the country has been fortunate that pilot light has been burning, in an unwavering manner, for decades."

"The Institute of Surgical Research is a bastion of excellence," says Richard Carmona, a former special forces medic who served as U.S. surgeon general between 2000 and 2006. "It's really a think tank — nobody has that ability like the military does." During his time in Vietnam, Carmona saw soldiers use rappel harnesses and scraps of parachute rigging to improvise tourniquets, an approach that seldom worked effectively.

The transition to effective, commercially made tourniquets was only possible, Carmona says, because USAISR was able to keep trauma research on the front burner, and to bring together world-class researchers and combat medics with real-world battlefield experience.

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[2] Butler, "Translating Military Advances in External Hemorrhage Control to Law Enforcement"
[3] Interview w/ Butler.
[4] This par sourced from USAISR publicity materials

Pivot Point

Kragh grew up in Goshen, New York, and attended the United States Military Academy at West Point hoping that he'd get to fly helicopters, he says, but within six months was identified as an academic high-flier and assigned to pre-med. After graduating medical school, he volunteered, along with many of his West Point classmates, for the U.S. Army Rangers — and it was while training with the Rangers that Kragh first saw the need for a solution to traumatic blood loss.

One night in 1992, right around Thanksgiving, Kragh says he was slogging across the Mojave Desert with his unit as part of a live-fire training exercise. Black Hawks buzzed overhead; in the distance, Kragh says he could hear the crackle of live rounds as ranger teams in helicopters focused machine-gun fire on their target. What Kragh couldn't see was the disaster that soon unfolded as a member of the helicopter team, a Ranger named Cpl. Jeffrey Palmer, wound up with his leg dangling in a machine gun's line of fire.

The exercise might have been simulated, but the stream of bullets that ripped into Palmer's thigh, shattering the bone and mangling his femoral artery, was very real. So was the blood that began gushing from his wounds as his helicopter circled down to the desert to get him to medical assistance. A fellow Ranger did the best he could to stop the blood-flow, compressing the wound and administering a saline drip to replenish the lost fluids.

"He basically did 1992 care -- there was no tourniquet, even though today we'd immediately have done that," Kragh says.

Within 20 minutes, Palmer had been flown to a nearly Naval hospital, where doctors provided additional saline to keep his blood pressure elevated. With blood still flowing from his wounds, Palmer grew colder and colder as the medical team poured more saline into his system. Soon he grew coagulopathic, a term indicating that the clotting agents in his blood had grown so diluted that he was bleeding more freely than when he arrived at the hospital. The trauma team had done everything right, by the standards of the day — but before the night was over, Palmer had died.

"Palmer bled to death, and it was on our watch," Kragh says. "That was really the pivot point for me."

Kragh arrived at the Naval hospital the next morning to debrief the medical team. Over the next few weeks, he spoke to Palmer's widow, and to his parents; later, he attended Palmer's funeral at Arlington National Cemetery, and rode by bus to his family's home in the Pennsylvanian mountains to mourn with his loved ones. A quarter-century later, Kragh's voice still thickens, and his eyes still glitter, as he recalls that journey.

"I'm acutely aware of what it's like to talk to the parents or the girlfriends or wives of the people who didn't make it," he says. "I know exactly what that's like, and I don't want other people to experience that."

Ancient Practice

The fact that nobody had a tourniquet on hand that night in the Mojave is all the more remarkable given that tourniquets are far from being a new technology. As early as 600 B.C., the ancient Indian physician Sushruta, known as the "father of surgery," used leather strips to stanch arterial bleeding, while ancient Greek physicians routinely used tourniquets to treat injuries.[5] But ancient doctors lacked the ability to repair damaged arteries, leaving patients with a stark choice: leave the tourniquet on, and face gangrene, or remove it, and bleed out.

"In the days of Hippocrates, the tourniquet was bound to fail," writes the Italian pathologist Guido Majno.[6] "The discovery had come too early." A few centuries later, the Romans used bronze rings to restrict blood-flow during surgery, but believed that using tourniquets to treat injured limbs would simply squeeze the blood out faster. Galen, the Roman-era physician, instead advised doctors to apply a "styptic" cocktail made from honey, eggs, and the fur clippings from a hare.[7]

The French surgeon Ambroise Paré experimented with Galen's potions in the 1500s, and found they worked somewhat better than cauterization with boiling oil, the standard treatment for a bleeding wound at the time. Paré also revived surgical tourniquet use when he took to binding limbs tightly with string before conducting amputations. It wasn't until 1674, however, that a French surgeon at the Siege of Besançon, in what is now eastern France, used tourniquets on the battlefield for the first time, using a stick to twist a soldier's bandage until the bleeding stopped.

Another French surgeon, Jean-Louis Petit, improved the design, adding a mechanical screw and a padded strap; still, such refinements didn't filter onto the battlefield, and during the Civil War, American soldiers were told simply to equip themselves with a rag and a stick with which to tighten it. Some commercial tourniquets were fielded during the first and second World Wars, but well into the 21st century American soldiers were routinely sent into battle without tourniquets, and advised simply to improvise as best they could with the materials they had in hand.[8]

The lack of progress was largely due to an entrenched suspicion that tourniquets did more harm than good. A soldier who lay for long hours wearing a tourniquet would almost certainly develop gangrene, and likely lose the limb and perhaps his life in the days that followed. Such problems fomented a mistrust of tourniquets that endured well into the 20th century.

"The tourniquet … has caused disasters," wrote Tuffier, the consulting surgeon to the French during World War I. "As soon as a tourniquet is seen in an ambulance it should be taken away."

Tourniquets were re-introduced during World War II, and a commercial tourniquet fielded, but the buckle-based design proved incapable of stopping arterial bleeding, and prone to working itself loose. Worse still, medics and soldiers were given conflicting and sometimes inaccurate information about how to use tourniquets. In training documents issued in advance of the Normandy landings, Allied medics were warned that any limb fitted with a tourniquet would

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[5] Saied, "Tourniquet in Surgery of the Limbs: A Review of History, Types and Complications"
[6] *The Healing Hand: Man and Wound in the Ancient World*
[7] *Invasion of the Body: Revolutions in Surgery*
[8] Mabry, "Tourniquet Use on the Battlefield" and Welling, "A brief history of the tourniquet"

likely require amputation, and instructed to avoid applying tourniquets to medical evacuees, but instead simply to send a tourniquet along with them, so that the device could be used in transit if necessary.

The limited efficacy of the buckled tourniquets, and the mixed messaging surrounding their introduction, fueled the perception that tourniquets were an instrument of last resort, and during the Korean War fewer than half of soldiers with major vascular injuries arrived at hospital wearing a tourniquet. Tourniquet use was patchy during Vietnam, too, with most soldiers having to use improvised tourniquets of limited effectiveness: an analysis of fatalities during the war found that more than 3,400 soldiers could likely have been saved had they been issued with effective tourniquets.

"Tourniquets have been a riddle for two millennia," Kragh says. "But this is not rocket science, and it is not secret. It's an awareness issue."

Bleeding to Death

Not long after Palmer's death, Kragh headed off to complete his medical training, and his Ranger unit shipped out to Somalia. It was there, during the Battle of Mogadishu in 1993 — the same firefight made famous in the film "Black Hawk Down" — that Holcomb first began paying attention to tourniquets, he says. As a combat surgeon, Holcomb saw first-hand that soldiers were dying because they were bleeding to death.

In one case, Sgt. 1st Class Robert Mabry, a combat medic assigned to an elite search-and-rescue team, treated a Ranger whose shinbone had been shattered by a gunshot wound. Like the medics who'd treated Palmer a year earlier in the Mojave, Mabry says he did things by the book, and the book said that using tourniquets did more harm than good.

Based on his training, Mabry didn't apply a tourniquet to the injured soldier; instead, he used a compression bandage to bind the wound, and carefully loosened the bandage throughout the night to allow the blood to circulate.

He learned too late that the tight bandage hadn't been able to stem the flow of arterial blood into the injured leg, he says, but had been enough to clamp shut the veins allowing blood to leave. That had reduced the bleeding at first, but the inbound arterial blood, trapped in the leg, eventually forced the pressure upwards, and blew out the still-forming clots in the injured limb. Loosening the bandage, meanwhile, only made it harder for the body to successfully seal off the wound. Lacking a tourniquet, Mabry's patient almost bled to death, he says.

While the medics on the ground weren't using tourniquets as a first line of defense, Holcomb says he saw some injured soldiers taking matters into their own hands. One injured Ranger lived because, after having his leg almost ripped off by an explosion, he fashioned a tourniquet out of a belt, and managed to twist it tight using a screwdriver.

"He used a belt as a tourniquet, and it saved his life," Holcomb says. "That sparked my interest."

After the dust settled from the battle, Mabry and Holcomb began to look more closely at the injuries their patients had sustained, and to compare them to the kinds of injuries sustained by U.S. troops in Vietnam. There were some obvious differences: improved body armor had dramatically reduced the incidence of fatal injuries to the chest and torso, for instance. But Mabry and Holcomb also found that deaths from penetrating wounds to the extremities — theoretically among the most survivable of injuries — remained unchanged. In both Vietnam and Somalia, they found, such injuries accounted for 7 percent of fatalities, with almost three quarters of wounded soldiers sustaining at least one extremity injury.[9]

For Mabry and Holcomb, the lesson was clear: America's military needed a new approach, and a more reliable way to stop blood loss from extremity injuries.

"You can trace a lot of the advances back to that episode, directly or indirectly," Holcomb says.

Vital Capability

Around the same time that Holcomb and Mabry were weighing the need for tourniquets in Mogadishu, Butler, at the time the director of a Navy biomedical research program, went in for minor knee surgery — the price of having played basketball during his college days.

His orthopedic surgeon planned to use a tourniquet to keep the surgical site clear of blood. For an hour-long knee operation, there was no issue with cutting off the blood supply to the lower leg, his surgeon told him. But Butler says that only raised more questions: "If we can leave them on for an hour in the operating room, why can't we leave them on in the battlefield?"

That realization led Butler to head a research team composed of Special Operations personnel and faculty at the Uniformed Services University of the House Sciences that authored a revolutionary article calling for special operations forces to be issued with tourniquets, arguing that for troops under fire, the ability to swiftly prevent exsanguination was a vital capability. All troops, he argued, should be equipped with tourniquets as part of their standard kit.

"A tourniquet is the most reasonable initial choice to stop major bleeding," he wrote. "The need for immediate access to a tourniquet in such situations makes it clear that all SOF operators on combat missions should have a suitable tourniquet readily available."

Published in 1996, Butler's paper triggered a gradual transformation in military medicine, culminating in 2001 with the formation of the CoTCCC, which now plays a critical role in bringing together USAISR researchers, civilian specialists, and combat medics to determine best practices for military trauma care. It also helped dramatically change the ways in which some Army medics thought about their jobs -- including Rob Miller, who was a medic with the 75th Ranger Regiment's 3rd Battalion when a copy of Butler's paper fell into his hands.

"It went against everything we knew to date," Miller says. As he discussed Butler's paper with other medics, Miller began to see Butler's point. "We looked at all the research, and it was sound," he says. "It was like, holy smoke, this makes great sense."

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[9] Mabry, "United States Army Rangers in Somalia: an analysis of combat casualties"

Miller took the paper to the Rangers' regimental commander, then-Col. Stanley McChrystal, and convinced him that the Rangers needed better training and technology to deal with combat casualties. Butler and Holcomb were called in to give lectures and help design training programs for the Rangers, and from 1998 onwards Butler's ideas, including tourniquet use, were made part of the standard training not just for medics, but for all members of the regiment.

"In the mid-to-late 90s, we'd already made the initial investment in embracing this technology," Miller says. "We were already light years ahead."

The approach paid off: despite seeing intense combat action, between 2001 and 2010 the 75th Ranger Regiment had no deaths from extremity hemorrhage, and saw preventable deaths account for just 3 percent of its fatalities, compared to 24 percent of all U.S. military fatalities.[10]

Still, when the Twin Towers fell in 2001, few units other than the Rangers and a few elite special ops groups were routinely training with tourniquets, and the ineffective World War II tourniquet remained the only officially approved device.

New Designs

Some medics took matters into their own hands: soon after 9/11, as his battalion prepared to deploy, Miller raided his local hardware store in search of tie-offs that could be repurposed as tourniquets, and persuaded his battalion commander to order 1,000 custom-made ratchet-based tourniquets.

"My unit was the first to go to Afghanistan, so we had to have something effective," Miller says. The new tourniquets weighed about a pound, Miller adds, but proved more effective than the World War II devices, and helped show that it was possible to create effective, battlefield-ready tourniquets using existing materials and knowhow.

As the war progressed, other medics followed Miller's lead, and began designing tourniquets of their own. One such design, which later evolved into the CAT, was dreamed up by a group of special operations medics who replaced the stick used in improvised tourniquets with a built-in windlass, and added a Velcro strap to hold the tightened windlass in place. The idea caught on, and by 2003, the medics' wives and mothers-in-law, back at their homes near Fort Bragg, were busy sewing together hundreds of CAT devices for soon-to-deploy soldiers.

By 2004, the CAT tourniquet had been transitioned to a commercial manufacturer and distributor. Still, it took several years, and many more preventable deaths, before tourniquet use began to spread beyond the Rangers and a few other elite groups. It was USAISR, then under Holcomb's command, that helped to push the technology forwards.

Holcomb, whose leadership philosophy is "a colonel and his memo can do almost anything," arranged a medical conference to bring together veteran combat medics, including Mabry and the SOF medics behind the CAT, with researchers from USAISR and beyond. During the conference, Holcomb startled USAISR's research physiologist, Tom Walters, by announcing that

[10] Kotwal, "Eliminating Preventable Death on the Battlefield" 2011

he would be working with Mabry to figure out which of the new tourniquet designs were actually effective, and to write guidelines for tourniquet use.

“One of the things that makes USAISR is that it has a commander, it doesn't have a director,” says Col. Shawn Nessen, the current USAISR chief. “Command is everything in the Army, and commanders can make things happen.”

Over the next few months, Walters — with help from Kragh, who’d arrived at USAISR in 2001 — brought himself up to speed on tourniquet literature, and began conducting tests to assess around 10 different tourniquet designs. Several devices performed well, but the CAT emerged as the top pick for front-line use, and in mid-2004, both USAISR and the CoTCCC recommended that the CAT be issued to all soldiers.

“The foundation had been laid, but it was falling on deaf ears,” Holcomb says. “But then the press and Congress got involved.” In March 2005, the Baltimore Sun published a hard-hitting article reporting that American troops were dying for lack of tourniquets, drawing national attention to the issue. Senators began asking questions, and congressional hearings were scheduled.

Within weeks, USSOCOM ordered that CAT tourniquets be issued to all deploying SOF units; before the month’s end, the Army Surgeon General recommended that all deploying troops receive the devices.

“The opportunity to improve care, and bring those guys home alive instead of dead, is worth fighting for,” Holcomb says. It was a vindication of his early, aggressive push for more tourniquet research, and for his continued advocacy for the devices.

Tourniquet Expert Geek of the United States

USAISR’s researchers often spend time in the field, re-immersing themselves in the realities of combat trauma, and a year after the Baltimore Sun article was published, Kragh arrived in Baghdad. A fresh wave of insurgency had just struck the Iraqi capital, and Ibn Sina Hospital, in the city’s Green Zone, was awash with combat casualties.

On his first evening in Iraq, Kragh says he took a shortcut through the emergency room on the way to the mess hall, and stopped to chat with the exhausted nurse on the front desk. Flicking through a clipboard, Kragh noticed with interest that a patient had been brought in wearing a tourniquet.

“No, that’s not interesting,” the nurse told him, yawning. “We get one of those every shift.” Startled, Kragh says he did the math in his head, and realized that if the nurse was right, then Ibn Sina was seeing tourniquet uses at 30 times the rate that any other facility had ever reported.

“It was colossal,” he says. “This was an opportunity to do some checking.”

These days, Kragh is arguably the world's foremost expert on prehospital tourniquet use, and signs his emails accordingly: "TEGOTUS — Tourniquet Expert Geek of the United States." When he arrived at USAISR in 2001, however, he had little clinical experience with tourniquets: he'd trained as an orthopedic surgeon, and spent his time dabbling in research and treating relatively minor injuries.

At USAISR, that began to change. Kragh served as a medical monitor on Walters' early studies of tourniquet efficacy, eventually becoming his research partner. "I basically became a tourniquet expert, and we started doing stuff together," he says. Eventually, Walters began to refocus on more foundational research, studying muscle injuries in rats, and Kragh, almost by accident, became USAISR's tourniquet specialist.

That meant that when he wandered into the Ibn Sina emergency room, Kragh immediately grasped the significance of the surge in tourniquet applications. It soon became apparent that the nurse hadn't been exaggerating, he says. Amidst a rash of IED and rocket attacks, soldiers and civilians were being rushed in every day with blast injuries to their extremities.

Kragh recalls hearing explosions nearby, and running to the emergency room to prepare for the injured patients he knew would soon be arriving.

"I'd got nothing else to do -- except sleep, which I didn't get much of," he says. He remembers, too, the way that the parched Baghdad air would grow noticeably more humid as injured patients gushed their life-blood out onto the floor of the emergency room. "Baghdad was just a vortex of violence," Kragh says. "There was just an epidemic of tourniquets, as far as I could see."

Tourniquet use had started to increase a few months before Kragh's arrival, as more soldiers were issued the devices, but there were still no standardized tourniquets, nor any clear guidelines on how to use them. Some patients received tourniquets moments after being injured; others were brought in without tourniquets, still dripping blood. Some had received improvised tourniquets; others wore World War II-era devices, or more recent designs like the CAT. Some patients' tourniquets were well-fitted; others wore tourniquets that hadn't been fully tightened, that had worked loose, or even that had been put on the wrong limb.

Along with Holcomb, who was also deployed at Ibn Sina, Kragh made it his mission to make sense of the chaos and carnage he saw around him.

"Holcomb and I are sitting there, in this tsunami of tourniquets," Kragh says. "We had a lot of people putting on a lot of tourniquets, so we saw a lot of stuff." It felt, in a way, as though the stars had aligned: even the hospital had once been a top research institute, named for the 11th century Persian physician who described the first recorded clinical trials.

"We kind of knew it -- if we didn't do it, who the hell was going to?" Kragh says.

Over the next seven months, Kragh ate and slept in the hospital, never more than a few moments' dash from the emergency room, and personally inspected virtually every tourniquet

that came in. He also developed a system for tracking the progress of all the patients he saw, taking gigabytes of digital photos, and amassing a huge collection of discarded tourniquets.

“It wasn’t a randomized, controlled trial — it was just me observing what the heck was going on,” he says. “But it was with eyes that knew something when they were seeing it.”

Kragh also made a point of visiting the morgue, a few steps from his sleeping quarters, to inspect the injuries of the soldiers who’d died before reaching the emergency room.

“We tend to kind of stick our head in the sand -- the people who write the books, the surgeons in the rear with the gear, only see the living, the ones who’ve survived,” Kragh says. “But the people who exsanguinate and die, they go to the morgue. So I went to the morgue.” As a surgeon, Kragh could read stories in the injuries that marked the bodies, and he found them all too familiar.

“You could stick your finger in the thigh of an isolated limb exsanguination,” he says. “And it's been written about in people going to Korea, the same damn thing. Why do we have these people die from isolated limb exsanguination when something could have been done for it with direct pressure, or a tourniquet?”

During his time in Iraq, Kragh documented the use of 428 tourniquets on 232 different patients; when he returned to the US, two nurses continued his work under USAISR supervision, ultimately amassing data on 1,212 tourniquet applications, far beyond anything previously reported.[11] As the data poured in, Kragh sorted it into “buckets” — improvised tourniquets vs. commercially made tourniquets, tourniquets added in the field vs. those applied in the emergency room, and so on — and, gradually, signals began to emerge from the noise.

“As the chaos of the cases gets sorted in certain ways, as you look at it from a certain view, then it comes into focus,” he says.

It soon became clear, for instance, that improvised tourniquets seldom worked, he says, and that the benefit of tourniquets evaporated if a patient had already entered shock by the time they were applied. But it also became apparent that when applied promptly, and removed in a timely manner, tourniquets could prevent exsanguination, while seldom if ever causing the limb damage that doctors had long feared. With the right training and guidelines, tourniquets could save lives.

“It became more and more clear -- we need to do this right. And we started to understand how to do it right by not doing it wrong,” Kragh says.

Kragh’s first report on his experiences at Ibn Sina, published in 2008, was immediately recognized as groundbreaking.[12]

[11] Kragh, “Tragedy Into Drama”
[12] See “Discussion” following Kragh, “Practical Use of Emergency Tourniquets to Stop Bleeding”

“At this point, there was still no good evidence that tourniquets were saving lives,” Butler says. “These studies really settled the tourniquet question once and for all. Without John’s research, the U.S. military would still be debating about whether or not tourniquets should be used.”

Kragh says that the expansion of tourniquet use from 2005 onwards set the stage for his success, both by providing him with cases to study, and by allowing growing numbers of soldiers and medics to see first-hand how effective tourniquets could be.

“That's a tremendous thing — when you see a gusher, and you make an intervention, and then there's no gusher,” Kragh says. “You put your arms up like it's a touchdown, almost; it's a visceral thing, and that's hard to argue with.” Still, he says, higher-ups and decision-makers who spent less time in battlefield situations needed scientific proof, and that’s where his studies proved vital.

“The naysayers, they needed evidence,” he says. “So we gave them evidence.”

That evidence made an impression: in December 2008, soon after Kragh’s first Ibn Sina study was published, the World War II tourniquet was finally withdrawn from active use by the U.S. military. For tourniquet advocates, that was a significant, symbolic rejection both of the inadequate technologies of the past, and of the suspicion with which tourniquets had long been viewed.

“Tourniquets were proposed in 1996, but without Dr. Kragh’s work, the U.S. military and the civilian sector would still be arguing about whether or not they were a good idea to use,” Butler says. “And now that argument is over — for all time, that argument is over.”

Damage Control

Pinned to the wall of his office at USAISR, Kragh keeps a faded 2011 obituary, clipped from the New York Times, memorializing Lt. Cmdr. Joseph Carmichael Jr., the chief engineer of the USS Bunker Hill. On May 11, 1945, Carmichael was in his office pushing papers when two Japanese kamikaze pilots smashed into the Bunker Hill. Instead of saving himself, Carmichael immediately ran down five flights of stairs, into the bowels of the blazing aircraft carrier, to keep the engines running and power the ship’s pumps. Thanks to Carmichael’s efforts, the Bunker Hill’s crew were able to tackle the fires that had broken out, execute a high-speed turn to slosh burning fuel out of the ship’s interior, and ultimately stay afloat for long enough to limp back to Pearl Harbor, saving both the ship and about 2,800 of its crew.[13]

There are obvious parallels, Kragh says, in dealing with a stricken battleship and a gushing wound. The first priority for Carmichael, he explains, was to stop the ship from sinking, but also to prevent the loss of power, without which he knew it would have been impossible to stay afloat. Similarly, the modern approach to casualty care, known as damage-control resuscitation, focuses on preventing patients from slipping into a downward spiral of blood loss, hypothermia, and coagulopathy.

[13] NYT, Oct 1 2011 -- “Joseph Carmichael Jr., a Carrier Hero, Dies at 96”

“Damage control is a naval term — we borrowed it,” Kragh points out. “They keep the ships floating, and we keep the patient floating.”

In practice, damage-control resuscitation means halting bleeding by any means necessary, then using whole fresh blood or component products — gently warmed, if possible — to restore blood pressure without blowing out clots, chilling the patient, or diluting the body’s clotting agents. That’s a revolutionary step forward from the kind of saline-based resuscitation attempted when Cpl. Palmer was injured in the Mojave in 1992 — and it’s a breakthrough that was largely enabled by the development of effective tourniquets, says Michael Dubick, USAISR’s task-area manager for Damage Control Resuscitation research.

“Resuscitation is going to have limited effectiveness unless we can stop the bleeding,” Dubick says. “If you can use a tourniquet early, and save as much blood in the body as possible, the casualty will do better.”

A tourniquet alone isn’t always enough to save a patient, adds Col. Andre Cap, USAISR’s resident blood-products expert, who has dedicated his career to putting more effective blood products — and especially the platelets that promote clotting — within reach of battlefield medics and forward aid stations.

“Tourniquets are, in and of themselves, probably the single biggest live-saving intervention we’ve made in the context of the last 15 years of war,” Cap says. “If you don’t get hemorrhage control, there’s nothing else to talk about, really.”

Cap leads the military’s efforts to field innovations like freeze-dried platelets, which battlefield medics could one day carry in their kits and mix with water to deliver at the point of injury. But such breakthroughs wouldn’t be nearly as effective, Cap says, without a fast, reliable way to halt the outflow of blood.

Besides enabling breakthroughs in transfusion and resuscitation, tourniquets have also made it possible for trauma surgeons to develop far more sophisticated treatments for soldiers brought to forward aid stations. Rasmussen, the former USAISR deputy, pioneered the use of one such technology: a shunt that diverts blood around an injury site, allowing surgeons to restore blood-flow to an injured limb. Though not a battlefield intervention, the shunts can be used in forward surgical units to extend the length of time that a tourniquet can safely be left in place before the flesh below the device begins to suffer irreversible damage.

“Without the shunt, you’ve got three or four hours to restore flow,” Rasmussen explains. “With the shunt in, the patient can wait a much longer time period. It extends that window of limb-salvage.” Rasmussen’s research suggests that shunting allows the full recovery of 93 percent of injured limbs. He estimates that shunts have been used in a third to a half of all extremity vascular injuries since the start of the war on terror. “It’s certainly been hundreds, if not thousands, during the course of the wars in Afghanistan and Iraq,” he says.

The bottom line, says Nessen, USAISR’s commander, who wrote a landmark textbook covering advances in combat surgery during the wars in Iraq and Afghanistan, is that tourniquet usage

allows more soldiers to live to be treated by surgeons, rather than exsanguinating on the battlefield, and also ensure that casualties are in better condition when they arrive at forward aid stations.

“Tourniquets are a pretty easy way to save a lot of people's lives,” Nessen says. “As long as that tourniquet gets on there, and the patient still has a heart-rate and a detectable blood pressure, if you get them to a surgeon in a reasonable amount of time then they should make it.”

Tourniquet of Choice

Thanks to Walters, Kragh, and Holcomb’s work, the CAT is now the tourniquet of choice for America’s troops, carried not just by medics, but by every frontline soldier.

Kragh is deferential to tourniquet-makers, and says individual manufacturers deserve the credit for the innovations that go into their products. The manufacturers themselves, however, see Kragh and his colleagues at USAISR as something akin to oracles.

“They have that knowledge at their fingertips, because they do it every day — not just with our products, but with other products from across the industry,” says John Steinbaugh, a former special forces medic who is now director of strategy for RevMedX, the manufacturer of numerous tourniquets and hemostatic dressings. “They can save you a lot of time and money.”

In practice, that means that a gentle suggestion — or, occasionally, a pointed question — from Kragh can often drive significant changes in tourniquet design. That can be as simple as a change in color, to differentiate civilian and tactical tourniquets, or involve more significant redesigns to increase efficacy, reduce pain to users, or eliminate the potential for confusion in moments of crisis.

That’s certainly been the case with the CAT, says Miller, who now serves as chief innovation officer for North American Rescue, the device’s distributor. The CAT has improved dramatically over the years, in large part thanks to Kragh’s continued scrutiny and evidence-based advice, Miller says.

“We wouldn’t be where we are today, and I wouldn’t have the knowledge and motivation to talk to people about tourniquets, without him,” Miller says. “None of the people who know about tourniquets would. Everything stems from that guy — it’s just the reality of it.”

For Kragh, though, the thousands of lives saved through his efforts to field and perfect the limb tourniquet are only half the battle, he says. One of the most moving scenes in the film “Black Hawk Down” focuses on Jamie Smith, a young Ranger who sustains a pelvic injury and, despite the heroic efforts of his comrades, gradually succumbs to blood loss.

“Everyone in the medical community has seen ‘Black Hawk Down’ many times,” says Anthony Pusateri, USAISR’s head of research.

Kragh knew Smith personally. On a glass partition by his office door, Kragh has written a row of numbers in dry-erase marker: the date of Jamie Smith's death during the Battle of Mogadishu, and a running tally of the number of people who've died from similar injuries in the intervening quarter-century. It's a personal reminder, he says, that the need for better hemorrhage control didn't end with the successful fielding of the CAT.

"We were literally kind of counting the days, and counting the deaths from that case," he says. "It's a concrete reminder for me."

The need not just for effective limb tourniquets, but also for a means of halting blood loss from junctional injuries -- pelvis or shoulder wounds that can't be treated with a conventional tourniquet -- was immediately apparent in the aftermath of the Battle of Mogadishu.

Mabry and Holcomb, in their analysis of the battle's casualties, found that wounds like those sustained by Smith accounted for 14 percent of fatalities in Somalia, compared to just 2 percent in Vietnam. A key lesson from the battle, they concluded, was not just that limb tourniquets should be carried widely and used promptly, but also that conventional tourniquets alone were not enough to meet the needs of the modern battlefield.

"Clearly, the management of choice for severe extremity hemorrhage is an effective tourniquet," they wrote. "But what about injuries not amenable to a tourniquet?"

That's a challenge that Kragh took to heart, especially as, thanks to the widespread adoption of the CAT, the rate of preventable deaths from extremity injuries began to fall, and junctional bleeding took over as the leading cause of preventable combat deaths.

In 2009, USAISR issued a call for new devices to tackle junctional injuries, and Kragh worked closely with a North Carolina contractor, Combat Medical Systems, to develop a device called the Combat Ready Clamp, or CRoC. The gadget works by pressing a tennis-ball sized compressor into the patient's groin, armpit, or even neck in order to halt bleeding.

Though somewhat unwieldy, the CRoC was rapidly fielded, and in 2012 was successfully used by U.S. medics to treat an Afghan man who had lost his leg. Most importantly, says Pusateri, USAISR's work demonstrated that junctional tourniquets were feasible, and that there was a significant unmet demand for the devices.

Out of that process came the SAM Junctional Tourniquet (SJT), a broad fabric band that looks like a plus-sized limb tourniquet, but includes an inflatable bulb that can apply targeted pressure to the pelvis, shoulder, and elsewhere. In 2013, the Food and Drug Administration gave the SJT its blessing, and the device first filtered onto the battlefield in 2014.

A few months later, word trickled back of the SJT's first successful use in a combat setting: a young Afghan National Army soldier had been shot in the thigh while engaging insurgents near a village in the south of the country, and rushed to a joint U.S.-Afghan aid station for treatment. En route, a CAT had been applied over the soldier's wound, but as the U.S. medics took a closer look, bright red arterial blood spurted into the air. Within minutes of the soldier's arrival, U.S.

medics were strapping the SJT in place and using its inflatable pressure-bulb to clamp off the blood-flow to the soldier's left leg. Thankfully, the soldier survived, and was soon stable enough to move to a local hospital for further treatment.[14]

The episode was the first time that the SJT had been used in pre-hospital casualty care, and the doctors who reported the case noted that the patient's injuries were remarkably similar to those that had killed Jamie Smith. In the 21 years since Smith's death, the doctors noted, research had moved trauma care "beyond past ineffective measures" and towards "interventions that may lead to saved lives on the battlefield."

Kragh's battle wasn't over — it took until October 2015 for military planners to decide how the SJT should be incorporated into combat medical kits, and to start distributing the devices more widely — but for the first time, there was an effective and widely available device capable of treating the kinds of injuries that killed Smith.

It's also due to Kragh's ability to collaborate productively with contractors and manufacturers, to the DOD's ongoing commitment to fund and support developers and manufacturers. "None of these things would have happened without DOD's investment, and without the involvement of labs like USAISR to push the field hard enough that people finally wake up and see there's a big need," Pusateri says.

Civilian Application

As word of the military's rediscovery of tourniquets filters through the trauma community, police departments and EMS services across the country are beginning to routinely provide tourniquets — and, in some cases, whole or component blood products — to first responders.

"When I arrived in Houston in 2008, it was abnormal to see tourniquets coming in," says Holcomb. Within weeks of his arrival at Houston's Memorial Hermann Hospital, however, Holcomb had introduced tourniquets to the emergency room. Over the next couple of years, he pushed for their adoption by the city's ambulance crews and police officers. By 2011, he says, it was abnormal to see patients who needed tourniquets coming in without them.

At Holcomb's hospital alone, at least 306 patients have been brought in wearing tourniquets since 2008. Records show that patients who received prehospital tourniquets were four and a half times less likely to die than those who arrived at the hospital with uncontrolled bleeding.

That aligns with past research showing that prehospital tourniquet use reduces mortality from penetrating injuries by as much as 57 percent.[15] Similar stories are playing out in emergency rooms across the country.

"Almost every week, I get an email from somewhere in the U.S. that documents someone whose life was saved with a tourniquet," Butler says. "It's indescribable to say how rewarding that is, to

[14] Klotz, "First Case Report of SAM® Junctional Tourniquet Use"
[15] Unpublished research from Holcomb.

see someone's husband or father or son or daughter saved with one of the things that the group I work with has helped to promote."

Interest in civilian tourniquet use skyrocketed after the Sandy Hook shootings, when a group of prominent public health and trauma experts formed the Hartford Consensus, a group dedicated to bringing cutting-edge trauma care, and especially tourniquet use, into the medical mainstream. With the backing of the White House, their efforts have now grown into a national campaign called "Stop the Bleed," which aims to make tourniquet training a part of basic first-aid classes, and to post bleeding control kits, including tourniquets, in public places alongside automated defibrillators.

Georgia has already funded a program to put bleeding control kits in the state's public schools, and California lawmakers are mulling a similar initiative; proponents hope that's just the tip of the iceberg.

"When we have the answers, our job is to be an accelerator," says Carmona, the former surgeon general, who helped establish the Hartford Consensus. That's especially true, he says, given the increasing use of high-powered weapons in mass-casualty events such as Sandy Hook, or the 2017 massacre in Las Vegas. "More and more, the injuries we're seeing in the civilian world look like combat casualties," he says. "It's unfortunate that we have to plan for this, but the reality is that these catastrophes do happen."

Changing the Game

The need to think about the bigger picture, and to push for civilian as well as military tourniquet use, is never far from Kragh's mind.

His office at USAISR is cluttered with Star Wars memorabilia, golfing trophies, a ceremonial sword, photographs of historical tourniquets, and other bric-a-brac, but looming over everything is a huge National Geographic world map — a reminder, Kragh says, of the global scope of his efforts.

Kragh used to monitor tourniquet usage around the world — from an airshow disaster in Nevada to a shark-bite epidemic in Réunion, an island east of Madagascar — but over time the incidents became so frequent that it was impossible to keep up. Still, Kragh knows that traumatic blood loss affects huge numbers of people, and says that, ultimately, is what motivated him to dedicate his professional life to the problem.

"The payback is *that*," Kragh says, gesturing at the map. "That's like 7.5 billion people. It's the whole freaking ladi-dadi everybody." He pulls out a battered brown-covered notebook with the number 15 scrawled on its cover. "The 15 is the 7.5 billion people on the planet, the world population today, and the next 7.5 billion to come," he explains. "It's a reminder for me to look at and see why I'm doing it, and what my scope and scale is."

Looking back on the fall night in 1992 when Cpl. Palmer died, Kragh says it's clear how far we've come. These days, he says, with proper tourniquets and effective damage-control

resuscitation, someone with Cpl. Palmer's injuries would survive about 95 percent of the time. "Palmer had it through *there*," he says, using a finger to trace an imaginary bullet's trajectory through his leg. "The mechanics of controlling that bleeding in the field — well, that'd be workable now. We'd have had a survivor."

And while the mainstreaming of tourniquets, and the development of new junctional devices, came too late for Palmer and Smith, Kragh takes comfort from the fact that in the future, fewer people will die from survivable injuries.

"It's really historic, to change first aid," he says. "We flipped tourniquet use on its head. It was absolutely last, and now it's absolutely first."

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