TACTICAL COMBAT CASUALTY CARE: TRANSITIONING BATTLEFIELD LESSONS LEARNED TO OTHER AUSTERE ENVIRONMENTS

Junctional Hemorrhage Control for Tactical Combat Casualty Care

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During historic, as well as more recent, conflicts, most combat casualties who die from their injuries do so in the prehospital setting. Although many of the injuries incurred by these casualties are nonsurvivable, a number of injuries are still potentially survivable. Of those injuries that are potentially survivable, the majority are truncal, junctional, and extremity hemorrhage. Novel and effective approaches directed toward prehospital hemorrhage control have emerged in recent years, some of which can prove useful in the management of junctional hemorrhage whether in a military or civilian setting. An initial comprehensive review of junctional tourniquets was conducted by the Department of Defense Committee on Tactical Combat Casualty Care in 2013. The objective of this article is to provide an updated review of junctional hemorrhage control efforts and devices as they apply primarily to military prehospital trauma management and Tactical Combat Casualty Care and to prompt further consideration and application of these devices in nonmilitary prehospital, austere, and wilderness environments. Four junctional tourniquets are currently cleared by the Food and Drug Administration (FDA) for junctional hemorrhage control, and 1 junctional tourniquet is also FDA-cleared for pelvic stabilization. As junctional hemorrhage control efforts progress, scientists need to continue to conduct research and clinicians need to continue to monitor the performance of junctional tourniquets, especially in conjunction with morbidity and mortality outcomes, for both military and civilian trauma patients.

Keywords: battlefield, junctional hemorrhage, junctional tourniquet, prehospital, Tactical Combat Casualty Care

Introduction

Junctional hemorrhage has been defined as compressible hemorrhage occurring at the junction of an extremity with the torso at an anatomic location that precludes the effective use of an extremity tourniquet, which includes the base of the neck.¹ Junctional hemorrhage is an externally compressible hemorrhage. Externally compressible hemorrhage can be controlled in the prehospital setting. Survival of trauma is associated with the time that has elapsed between injury and receiving a required intervention or capability. Thus,

nonmedical and medical first responders must have the capability to successfully compress and control junctional hemorrhage through appropriate training and effective use of junctional tourniquets.

Background

Over the past decade, the application of tourniquets for extremity hemorrhage has become more ubiquitous in both the military and civilian settings. As this transpired in the US military, junctional hemorrhage surpassed extremity hemorrhage as the most common cause of battlefield death from externally compressible, and thus potentially survivable, hemorrhage.² Of note is that junctional hemorrhage is also a significant component of what has become known as the “dismounted complex blast injury.”³ Thus, another factor that contributed to the increased incidence of death from junctional hemorrhage on the battlefield was the expanded use of antipersonnel

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pressure-activated improvised explosive devices (IEDs). Specifically, the comprehensive Eastridge et al study of US combat fatalities in the recent conflicts of Afghanistan and Iraq reported that 17.5% (171 of 976) of potentially survivable prehospital deaths resulted from junctional hemorrhage.²

In January 2013, a US Central Command and Department of Defense (DoD) Joint Trauma System report on prehospital trauma care in Afghanistan highlighted the above findings and advocated for more research and expanded fielding of junctional tourniquets.⁴ In August 2013, the assistant secretary of defense for health affairs directed the Committee on Tactical Combat Casualty Care (CoTCCC) to consider all devices for junctional hemorrhage that had been cleared by the Food and Drug Administration (FDA).⁵ At that time there were 4 such devices for the indication of junctional hemorrhage control: the Abdominal Aortic and Junctional Tourniquet (AAJT; Compression Works, Birmingham, AL); the Combat Ready Clamp (CRoC; Combat Medical Systems, Fayetteville, NC); the Junctional Emergency Treatment Tool (JETT; North American Rescue, Greer, SC); and the SAM Junctional Tourniquet (SJT; SAM Medical Products, Portland, OR). Additional details and photos of these devices can be found on manufacturer websites as well as in the 2015 *Wilderness & Environmental Medicine* article on hemorrhage control techniques by Drew et al.⁶

The CoTCCC considered these 4 devices and recommended 3 junctional tourniquets (CRoC, JETT, SJT) for inclusion in the Tactical Combat Casualty Care (TCCC) guidelines and for rapid fielding to prehospital providers on the battlefield.¹ After 3 years, all 4 of these junctional tourniquets remain on the market as an option in the management of junctional hemorrhage, and there are no new FDA-cleared junctional tourniquets. Research studies and case reports have been published on these junctional tourniquets during the interim. Thus, another review of the medical literature is warranted.

CoTCCC Review

In 2013, the CoTCCC reviewed the medical literature and recommended 3 junctional tourniquets (CRoC, JETT, SJT).¹ The CoTCCC also modified the TCCC guidelines to reflect the committee's recommendation for junctional hemorrhage control during the phases of Tactical Field Care and Tactical Evacuation, as follows: "If the bleeding site is appropriate for use of a junctional tourniquet, immediately apply a CoTCCC-recommended junctional tourniquet. Do not delay in the application of the junctional tourniquet once it is ready for use. Combat Gauze (Z-Medica, Wallingford, CT)

applied with direct pressure should be used if a junctional tourniquet is not available or while the junctional tourniquet is being readied for use."

The 2013 CoTCCC review also noted the following 5 points: 1) With preventable death from extremity hemorrhage greatly reduced by extremity tourniquet use by the US military, junctional hemorrhage surpassed extremity hemorrhage in frequency as a cause of battlefield mortality; 2) the incidence of combat death from junctional hemorrhage due to expanded use of antipersonnel, pressure-activated IEDs had increased; 3) junctional hemorrhage is a component of what has become known as dismounted complex blast injury; 4) pelvic fractures may be seen in association with junctional bleeding in dismounted IED attacks; and 5) data suggest dismounted IED casualties with traumatic amputation higher than a below-the-knee amputation warrant empiric application of a pelvic binder.

Since the 2013 CoTCCC review, no prospective trials to support the efficacy of current FDA-cleared junctional tourniquets on casualties in the prehospital environment have been published. Available evidence for junctional tourniquets continues to be derived from laboratory studies and case reports.

Studies Comparing the 4 Junctional Tourniquets

Five comparison studies were conducted on the 4 FDA-cleared junctional tourniquets. Metrics from these studies are summarized below and in the [Table](#).

1. Kotwal et al (2013)¹: A CoTCCC review of junctional tourniquets. The JETT and SJT were less expensive than the AAJT and CRoC. The AAJT and SJT weighed less than the CRoC and JETT. The CRoC consumed the least space by volume.
2. Kragh et al (2013)⁷: A laboratory assessment of out-of-hospital interventions to control junctional bleeding from the groin in a manikin model. The median and mean time to stoppage of bleeding was lowest for the SJT. The median and mean blood loss volume was lowest for the SJT.
3. Kragh et al (2014)⁸: A study of military medic use of junctional tourniquets in simulated prehospital trauma care. Nine medics used 4 different junctional tourniquets (CRoC, AAJT, JETT, and SJT). All tourniquets used were safe under the conditions of the study. Both the SJT and CRoC had high effectiveness percentages (the difference was not significant). The SJT and CRoC had fast times to effectiveness (the difference was not significant). Users preferred the SJT and CRoC (the difference was not significant).

Table. Metrics from studies comparing 4 FDA-cleared junctional tourniquets

Study	Metric	Junctional tourniquet			
		AAJT	CRoC	JETT	SJT
Kotwal et al ¹	Cost			X	X
	Weight	X			X
	Volume		X		
Kragh et al ⁷	Time to stop bleeding				X
	Blood loss volume				X
Kragh et al ⁸	Effectiveness		X		X
	Time to effectiveness		X		X
	Medic ranking		X		X
Kragh et al ⁹	Effectiveness		X	X	X
	Time to effectiveness		X		X
	Pain		X	X	X
	Subject rating		X		
Chen et al ¹⁰	Effectiveness	X	X		
	Time to effectiveness			X	X
	Medic ranking	X			X

An “X” marks a positive comparison metric for the device as noted in the study of origin.

AAJT, Abdominal Aortic and Junctional Tourniquet; CRoC, Combat Ready Clamp; JETT, Junctional Emergency Treatment Tool; SJT, SAM Junctional Tourniquet.

4. Kragh et al (2015)⁹: Differential performance of models of four junctional tourniquets (AAT, CRoC, JETT, SJT) were assessed in a laboratory setting on 10 human volunteers. The CRoC, SJT, and JETT were most effective (difference was not significant). All tourniquets were applied safely and successfully in at least 1 instance each. The pain varied by model with subjects assessing the CRoC as most tolerable. The CRoC and SJT were fastest to apply. Users ranked the CRoC and SJT equally as performing best.
5. Chen et al (2016)¹⁰: A study of junctional tourniquet use in simulated prehospital care. Fourteen medics used 4 junctional tourniquets (CRoC, AAJT, JETT, SJT). All tourniquet uses were safe. By the time the first 5 testers were done, all 3 of the AAJT models had been broken. The CRoC and AAJT had the highest percentage effectiveness (the difference was not significant). The SJT and JETT had the fastest mean times to effectiveness (the difference was not significant). The SJT and AAJT were most preferred by users (the difference was not significant). For each user's most preferred model, the SJT, AAJT, and JETT were most preferred (the difference was not significant).

level of the infrarenal aorta in order to occlude blood flow. Package insert changes that have occurred over the past 3 years include removal of the AAJT's previous relative contraindication for penetrating abdominal trauma; a change in the AAJT's application time limit from 1 hour to 4 hours; and, most recently, a change in the AAJT's application time limit to 4 hours in junctional areas (inguinal and axilla) and 1 hour in the abdominal area.

Three AAJT case reports can be found in the medical literature.^{11–13} The first case report occurred on a military prehospital battlefield rotary wing transport and reported on a casualty with traumatic bilateral lower extremity amputations who concurrently received 2 units of packed red blood cells (PRBCs) and 2 units of fresh frozen plasma and ultimately survived.¹¹ The second case report occurred in a civilian hospital emergency room and reported on a casualty with a gunshot wound to the left upper arm and axilla who concurrently received 4 units of PRBCs and ultimately survived.¹² The third case report occurred in a civilian hospital emergency room and reported on a casualty with a gunshot wound to the left proximal thigh who concurrently received 4 units of PRBCs and ultimately survived.¹³

Two studies described effective control of blood flow in the common femoral artery in human subjects.^{14,15} One study evaluated the physiologic consequences of AAJT application to control hemorrhage in a swine model.¹⁶ This study looked at the physiologic effects of

Studies for Individual Junctional Tourniquets

AAJT

The AAJT is a pneumatic belt designed to provide continuous pressure above a junctional area or at the

a 2-hour abdominal application of the AAJT to control groin hemorrhage. Findings included ischemia-induced hyperkalemia and metabolic acidosis associated with AAJT application that were life-threatening in spontaneously breathing subjects. To prevent life-threatening consequences, cardiopulmonary resuscitation appeared to be necessary when the AAJT was released.

CROC

The CROC is a clamp designed to exert mechanical pressure directly over the wound or indirectly over a junctional area (inguinal and axilla) to occlude underlying blood vessels and stop hemorrhage. Application time limit is 4 hours.

One CROC case report can be found in the medical literature.¹⁷ This case report occurred on a military prehospital battlefield rotary wing transport and reported on a casualty with traumatic left leg and hindquarter amputation who was stable until transferred to an Afghan hospital with limited resources. The hospital designated the casualty as expectant and removed the clamp, and the casualty exsanguinated.

One study described effective control of blood flow in human subjects.¹⁸ Another study evaluated the long-term effects of combat-ready clamp application to control junctional hemorrhage in swine.¹⁹ This study examined the functional recovery of pigs' hind legs 2 hours after CROC application. Findings included mild and reversible ischemic injuries with 2-hour inguinal application of CROC, which delayed full recovery of limb function by a few days. Additionally, the 2-hour umbilicus application of the CROC resulted in extensive muscle necrosis with functional disabilities.

JETT

The JETT has components that include a belt assembly and 2 windlass T-handle with trapezoidal pad systems. The JETT can be used for the management of junctional hemorrhage and for the treatment of suspected pelvic fracture and instability; it is not cleared by the FDA for the latter but could be used off label for this indication. Application time limit is 4 hours.

No case report was found in the medical literature. One study showed effective control of blood flow in the common femoral artery of a perfused cadaver model.²⁰ Another study used imaging to evaluate the compressive function of the JETT in the reduction of pelvic ring injuries in a cadaver model.²¹ Findings showed the JETT capable of effectively reducing an anteroposterior compression type III injury pelvic ring disruption and injury by approximating inlet and outlet dimensions toward predisruption measurements.

SJT

The SJT has components that include a belt assembly and 2 pneumatically inflatable bladders or target compression devices. The SJT can be used for the management of junctional hemorrhage (inguinal and axilla) as well as the treatment of suspected pelvic fracture and instability and is cleared by the FDA for both indications. Application time limit is 4 hours.

One SJT case report can be found in the medical literature.²² This case report occurred in a military prehospital battlefield battalion aid station and reported on a casualty with a gunshot wound to the left proximal thigh who ultimately survived. Another study evaluated the SJT in a perfused cadaver experiment simulating inguinal or axillary wound hemorrhage.²³ The SJT was shown to be safe and effective in hemorrhage control, and the target compression devices required pressures approximately equal to or lower than manual pressure to achieve hemostasis in junctional regions.

Other Junctional Tourniquet Studies

One article conducted a review to record the experiences of several medical personnel in their junctional tourniquet training of users to provide a guide for future trainers.²⁴ Another article assessed and compared 2 junctional tourniquets (CROC, JETT) during an advanced medical first responder course.²⁵ In this study, users ranked the JETT higher than the CROC on all parameters, including effectiveness on the battlefield, ease of use, speed of application, and not slipping in use.

Junctional Hemorrhage Control and Pelvic Stabilization

For pelvic stabilization in the prehospital setting, data suggest dismounted casualties with a traumatic amputation higher than below-knee amputation warrant empiric application of a pelvic binder.¹ Combat medics from the United States and United Kingdom carry pelvic binders to use on individuals with suspected pelvic fracture and instability.^{1,4,15} Pelvic fractures may be associated with junctional hemorrhage, particularly during dismounted IED attacks.^{1,3,15} In addition to management of junctional hemorrhage, some junctional tourniquets have potential to reduce and stabilize pelvic fractures.^{15,21}

Department of Defense Fielding of Junctional Tourniquets

Efforts have been varied as they relate to the procurement and regulated fielding of junctional tourniquets throughout the DoD. The US Army, through the recommendation of its Capability Development

Integration Directorate, selected and integrated the SJT into the Combat Medic Medical Equipment Set.²⁶ The US Army also conferred a Greatest Innovation Award for 2015 on the SJT, as the SJT was developed through collaborative efforts of scientists at the US Army Institute of Surgical Research in strategic partnership with the US Army Medical Department Center and School as well as outside universities and companies.

Although the US Special Operations Command has also formally fielded the SJT through casualty evacuation sets, subordinate commands continue to use various junctional tourniquets through recommendations from unit surgeons and directives from unit commanders. Junctional tourniquet fielding efforts for the US Air Force, US Navy, and US Marines are currently unknown. Overall, a unified DoD-wide Medical Rapid Fielding Initiative for junctional tourniquets is needed.

Conclusions

Four junctional tourniquets (AAJT, CRoC, JETT, SJT) are currently FDA-cleared for junctional hemorrhage control, and 1 junctional tourniquet (SJT) is also FDA-cleared for pelvic stabilization. Three junctional tourniquets (AAJT, CRoC, SJT) are indicated for both inguinal and axilla junctional hemorrhage control. Three junctional tourniquets (CRoC, JETT, SJT) are currently CoTCCC-approved for junctional hemorrhage control. Three junctional tourniquets (AAJT, CRoC, SJT) have published case reports documenting use and potential contributions to lives saved in the prehospital setting. Two junctional tourniquets (JETT, SJT) have a dual purpose and the potential for both hemorrhage control and pelvic stabilization. Two junctional tourniquets (CRoC, SJT) are notable for the most positive metrics as reported in recent studies. Abdominal application of junctional tourniquets for 2 hours appear to have potential for further harm.

As junctional hemorrhage control efforts progress, scientists need to continue to conduct research and clinicians need to continue to monitor the performance of junctional tourniquets, especially in conjunction with morbidity and mortality outcomes, for both military and civilian trauma patients. Although 2 case reports reviewed describe the use of junctional tourniquets in the setting of a civilian emergency room, these devices should also be considered for further nonmilitary application such as with emergency medical services, law enforcement, and other first responders involved with care in prehospital, austere, and wilderness environments.

Disclaimer: The views, opinions, and findings contained in this article are those of the authors and should not be construed as official or reflecting the views of the Department of Defense unless otherwise

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