# REPORT DOCUMENTATION PAGE

*Form Approved*
**OMB No. 0704-0188**

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Service, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.
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| 1. REPORT DATE *(DD-MM-YYYY)* | 2. REPORT TYPE | 3. DATES COVERED *(From - To)* |
|---|---|---|
| xx-xx-2010 | Master of Military Studies Research Paper | September 2009 - April 2010 |

**4. TITLE AND SUBTITLE**
Increasing Survivability on the Battlefield: Hemorrhage Control and the Joint Theater Trauma System

**5a. CONTRACT NUMBER**
N/A

**5b. GRANT NUMBER**
N/A

**5c. PROGRAM ELEMENT NUMBER**
N/A

**6. AUTHOR(S)**
Kellstrand, Amy A.

**5d. PROJECT NUMBER**
N/A

**5e. TASK NUMBER**
N/A

**5f. WORK UNIT NUMBER**
N/A

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
USMC Command and Staff College
Marine Corps University
2076 South Street
Quantico, VA 22134-5068

**8. PERFORMING ORGANIZATION REPORT NUMBER**
N/A

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
N/A

**10. SPONSOR/MONITOR'S ACRONYM(S)**
N/A

**11. SPONSORING/MONITORING AGENCY REPORT NUMBER**
N/A

**12. DISTRIBUTION AVAILABILITY STATEMENT**
Unlimited

**13. SUPPLEMENTARY NOTES**
N/A

**14. ABSTRACT**
The leading cause of preventable deaths on the battlefield is exsanguination, and 70.5% of casualties in OIF/OEF have suffered serious extremity injuries with hemorrhage control as the primary focus of prehospital medical treatment. Developments in hemorrhage control and the implementation of the JTTS have facilitated critical prehospital improvements to increase the survivability of battlefield casualties. Five hemostatic agents appear promising; QuikClot, HemCon, QuikClot Combat Gauze, HemCon Chitoflex, and Self-Expanding Hemostatic Polymer. Differences in appropriate usage, cost, and side effects influence FDA and military approval. The CAT tourniquet is currently the best prehospital tourniquet when applied properly. The JTTS, the world's largest and most complex trauma system, was designed to track, trend, and report performance processes to improve medical care within combat theaters. It has directly influenced critical medical advances to achieve the lowest mortality rates in U.S. history.

**15. SUBJECT TERMS**
Combat trauma, Survivability on battlefield, Joint Theater Trauma System, hemorrhage control, damage control, hemostatic agents, QuikClot, HemCon, Self-Expanding Hemostatic Polymer, tourniquet

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| | | | | | Marine Corps University / Command and Staff College |
| a. REPORT | b. ABSTRACT | c. THIS PAGE | UU | 53 | 19b. TELEPONE NUMBER *(Include area code)* |
| Unclass | Unclass | Unclass | | | (703) 784-3330 (Admin Office) |

United States Marine Corps
Command and Staff College
Marine Corps University
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Quantico, Virginia 22134-5068

MASTER OF MILITARY STUDIES

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# INCREASING SURVIVABILITY ON THE BATTLEFIELD: HEMORRHAGE CONTROL AND THE JOINT THEATER TRAUMA SYSTEM

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF MILITARY STUDIES

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AY 09-10

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Date: 04/09/10

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Approved: _____
Date: 9 April 2010

## Executive Summary

**Title:** Increasing Survivability on the Battlefield: Hemorrhage Control and the Joint Theater Trauma System

**Author:** Major Amy A. Kellstrand, United States Marine Corps

**Thesis:** Developments in hemorrhage control and the implementation of the Joint Theater Trauma System have facilitated critical improvements that have increased the survivability of severely-injured casualties on the battlefield.

**Discussion:** The leading cause of *preventable* deaths on the battlefield is exsanguination, and 70.5% of casualties in OIF/OEF have suffered serious extremity injuries with hemorrhage control as the primary focus of prehospital medical treatment. Developments in hemorrhage control and the implementation of the Joint Theater Trauma System (JTTS) have facilitated critical prehospital improvements to increase the survivability of battlefield casualties.

Damage control describes an abbreviated priority of procedures designed to control hemorrhage, restore blood flow, and prevent compartment syndrome when applied to extremity vascular injuries. The goal is to stabilize the physiological processes of a casualty, then evacuate to the most suitable medical treatment facility to undergo definitive surgery and rehabilitation.

The JTTS has assisted with the identification and development of hemostatic agents that arrest life-threatening bleeding and have self-application capabilities. Five hemostatic dressings appear promising; QuikClot, HemCon, QuikClot Combat Gauze, HemCon ChitoFlex, and Self-Expanding Hemostatic Polymer. Each has demonstrated effective hemorrhage control properties when used in combat scenarios. Differences in appropriate usage, cost, and side effects influence FDA and military approval. Currently, QuikClot and HemCon are the most widely-used, but continuous development and modifications may result in their replacement by more recently developed hemostatic dressings.

Tourniquet application is a simple, fast, and inexpensive way to stop arterial flow to the limb in life-threatening situations. The Combat Application Tourniquet is the best prehospital tourniquet available as it can be self-applied with one hand or a trapped limb. It is compact, durable and requires minimal training. The TCCC recommends its use in situations of uncontrolled bleeding, limb amputation, or when a casualty is in shock with a contributing exsanguinating wound.

The JTTS is the world's largest and most complex trauma system, designed to track, trend, and report performance processes to improve medical care within combat theaters. The JTTR acts as a primary collection source to capture and track injury data to be examined through a research database. The performance improvement system accesses this data to identify shortfalls, develop and execute performance initiatives, and monitor the outcomes. Medical advances, information management procedures, personal protective equipment, and evacuation equipment and procedures are a few areas that the JTTS has influenced to increase the survivability of battlefield casualties.

**Conclusion:** The KIA rate amongst U.S. servicemembers due to combat action in Iraq started at 20% in 2003 and has been reduced to an overall 9.9% in Iraq and 12.3% in Afghanistan. The development and implementation of the Joint Theater Trauma System has initiated and directly influenced critical medical and technological advances to achieve the lowest mortality rates in United States history. Extremity injuries will continue to be seen with higher frequency as weapons become more destructive and protective gear becomes more effective, but with continued data collection and research, survivability rates will continue to increase.

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## Preface

I began this project as a result of a conference with one of my instructors, Dr. Rebecca Johnson. After a brief discussion about my interest in medicine, a field in which I possessed extremely limited knowledge, she recommended that I research some aspect of military medicine that I found particularly interesting. I began with a general focus on trauma and after a more specific search of the development of the Joint Theater Trauma System, I found myself consumed in several articles that discussed ways to increase the survivability of casualties on the battlefield. This caught my attention as I had recently completed two deployments to Iraq. I became intrigued with the current methods recommended to prevent exsanguination, the leading cause of preventable death on the battlefield. The combination of modern technology used to develop advanced hemostatic agents, combined with variations of a primitive device, the tourniquet, used as far back as the Greeks and the Romans, appears to produce the greatest ability to arrest blood flow and keep severely-injured casualties alive. As our enemy's weapon of choice in Iraq and Afghanistan seems to be the improvised explosive device, the cause of many extremity injuries, this topic was not only of personal interest to me, but more importantly, may be of interest to those deploying to hostile areas of the world.

**Acknowledgements**

This project is a compilation of the hard work of many motivated individuals. The positive encouragement and professional advice received from the individuals listed below served to keep me motivated. I would like to thank the Marine Corps University for the opportunity to address this topic as the survivability of our comrades is of great concern to members of the military, our deploying civilian counterparts, and the extensive network of families that support each and every member of the U.S. and Allied Armed Forces.

My mentor, Dr. Rebecca J. Johnson worked tirelessly to keep me on track and provided valuable insight and motivation with her energy and persistent enthusiasm. Thank you for your guidance and patience throughout this project.

Rachel Kingcade, reference librarian at the Alfred M. Gray Research Center and Andrea Hamilton, Communications Assistant from the Leadership Communication Skills Center of Marine Corps University made the daunting task of taking on this project seem easy with constructive research advice and editorial assistance.

Captain Ray Wiss, M.D., Canadian Forces, and Jane Hulse, British Medical Officer graciously offered their expertise from experiences in Afghanistan. Ray, I look forward to reading your most recent work, "FOB DOC".

Tahirih Fusscas, Reference Librarian, E. R. Stitt Library, the National Naval Medical Center, set me up with seemingly unlimited access to the library's medical research database.

My Family: Mom, Dad, Eric and Michael, you gave me the support and encouragement I needed to stay motivated. Thank you.

## Introduction

The majority of deaths on the battlefield fall into three main categories: total body disruption, severe brain injury, and hemorrhage.[1] Even with current technological advances, little can be done to prevent death in the first two cases; however, improvements in hemorrhage control at the point of wounding can significantly enhance survivability in the third case.

The prehospital period is the most critical in regards to combat casualty care. Recent data suggests that as many as 90 percent of combat deaths occur before the casualty presents at a medical treatment facility and that a significant percentage of these deaths are preventable with proper and timely intervention at the point of injury.[2] Research also reveals that the leading cause of *preventable* deaths in combat is due to hemorrhagic shock and exsanguination, and it is estimated that up to 90 percent of these deaths can be avoided.[3] Developments in hemorrhage control and the implementation of the Joint Theater Trauma System (JTTS) have facilitated critical improvements that have increased the survivability of severely-injured casualties on the battlefield.

Since physicians and skilled medical providers are rarely present at the point of injury, it is critical to improve existing life-saving interventions that can be performed within minutes of wounding. These simple measures increase the survivability of battlefield casualties. This paper will focus specifically on this critical prehospital scenario and some of the developments and implementations that have increased the survivability of combat personnel. The development of two promising hemostatic dressings, QuikClot and HemCon will be addressed as well as improvements in tourniquet design and use, with focus on damage control procedures to prevent exsanguination.

The JTTS has played an instrumental role in streamlining advances to improve survivability on the battlefield. Progress in evacuation and information management procedures have resulted in a decrease in time from the point of injury to the commencement of definitive surgery. In addition, improvements to personal protective equipment have resulted in less severe injuries to the torso region. Finally, the incorporation of pre-deployment training with a focus on current trends within theater has served to effectively prepare soldiers and medical personnel to provide appropriate casualty care at the point of injury.

Combat casualty care has undergone significant advances in the past ten years to become more effective in a changing battlefield environment. Operations within Iraq and Afghanistan have demonstrated a shift in combat operations from large, conventional type wars to asymmetric and unconventional counterinsurgency operations. These counterinsurgency operations require considerable joint integration and coordination amongst the various services and contributing agencies as smaller combat units operate throughout increasingly expansive geographic regions. This shift has resulted in the need for a centralized medical system (the JTTS) to provide organized medical care as well as track and research trends in wounding patterns and tactical conditions in order to paint a more comprehensive picture of overall theater operations.

Upon implementation of the JTTS, some significant differences were identified between civilian and combat casualty care. These differences are important to address because few medical personnel had experience in combat trauma at the onset of Operation Iraqi Freedom/Operation Enduring Freedom (OIF/OEF) as the previous major conflict was Vietnam. Additional training was paramount to prepare medical personnel for the unique situations they would encounter.

Combat casualties often result in far more devastating injuries than those encountered in the civilian environment. Many are the result of high-velocity penetrating injuries due to explosives, munitions, and missiles and have the potential to cause massive soft-tissue destruction. Massive complex trauma, such as traumatic limb amputation is common on the battlefield and the management of these extremity vascular injuries presents unique and demanding challenges to surgeons accustomed to operating in the civilian arena.[4] Serious civilian trauma is usually the result of sharp, penetrating stab wounds or low-velocity, small-caliber munitions commonly seen as a result of inner-city violence, or blunt trauma injuries routinely a result of vehicle crashes.[5]

The JTTS addressed this shortfall in combat medical experience and developed standardized pre-deployment training for medical personnel. Focus was placed on the fundamental differences of combat versus traditional civilian trauma care to include unique wounding patterns received in combat and the hostile conditions within which medical personnel are required to work. Responding medical personnel needed to be prepared to experience conditions involving hostile fire that can inhibit or even prevent a medic's ability to provide treatment. Also, medical equipment is limited to that which is carried by the casualty or attending medic. In addition, tactical considerations often dictate that the successful accomplishment of the mission take precedence over casualty care, especially if care given has the potential to result in further casualties. Finally, the availability of casualty evacuation is highly variable due to the location and tactical situation involved.[6]

The JTTS also prepares medics to face unique complications that must be taken into account while providing casualty care in combat. A medic must not only assess the patient to identify the proper intervention, but also the appropriate time to carry out required treatment as

the proper intervention at the wrong time could lead to further casualties.[7] For example, while under fire, a medic should focus on life-threatening injuries only. Excessive evaluation and treatment may put both the rescuer and the casualty in unnecessary danger of hostile fire. Detailed examinations and procedures that require additional lighting or excessive movement should take place once the casualty has gained access to a covered position. Therefore, combat medical personnel are faced with a difficult situation as they strive to maintain balance amongst three critical goals. They must be able to balance their duty to provide optimum casualty care against the prevention of additional casualties and the importance of successful mission accomplishment.

The JTTS has also drawn from the efforts of allies to improve combat trauma response. The Canadian Forces Health Services and U.S. Army Medical Department have worked together over the last several years to provide optimum training for deploying medical personnel. U.S. and Canadian military surgeons take part in a program established at civilian trauma training centers. One-month rotations through these centers provide surgeons with greater experience in trauma care during peacetime and prior to combat deployments.[8] Both countries send medical personnel to attend the Joint Trauma Combat Management Course provided by the Army Medical Department.[9] Prehospital medical providers attend training courses that use scenario-based "real-time" training, simulator, and live tissue training based on data collected by the JTTS. Feedback from these courses and personnel returning from deployment is used to help guide future training and equipment developments for prehospital trauma care.[10] For example, the *Emergency War Surgery Handbook* has been used as a guide for surgeons for decades; however, Chapter 16 of the *Prehospital Trauma Life Support Manual* was initially used solely by Special Operations Forces. As a result of feedback from deployed personnel, it has now been

implemented by many conventional forces and medics because of its straightforward instructions and applicability.[11] Additionally, training is based on Tactical Combat Casualty Care (TCCC) principles. TCCC is a set of principles aimed to prevent further casualties, accomplish the tactical mission, save the maximum number of lives, and increase survivability of the injured. It is based on treating the leading preventable causes of death on the battlefield.[12]

This paper will discuss several means by which the JTTS has served to increase survivability through improvements in prehospital trauma care throughout recent operations within Iraq and Afghanistan. Specific focus will be given to the development and modifications to hemostatic dressings as well as improvements in tourniquet design and recommended application. A more general focus will continue to describe the structure of the JTTS as well as how it has improved the ability to track patients through each echelon of medical care by means of the Joint Theater Trauma Registry (JTTR), the performance improvement program, and improved information management procedures. Finally, a discussion of how the JTTS has influenced advancements in air evacuation procedures and onboard medical equipment will demonstrate a further increase in survivability rates today.

## Hemorrhage Control

According to the JTTR, 70.5% of the casualties in OIF/OEF have suffered serious extremity injuries with hemorrhage control as the primary focus of medical treatment.[13] Therefore, the achievement of effective hemorrhage control in the prehospital setting has proven critical to increase survivability rates amongst casualties. In the past few years, tremendous advances have been made in the development of advanced hemostatic products to arrest

traumatic bleeding. These products hold the promise of saving lives in both civilian and military situations.[14]

Developments in hemostatic agents as well as improved tourniquet design and recommended use together have contributed to significant advances in hemorrhage control. QuikClot and HemCon are two of the most promising new hemostatic agents that have been tested and fielded by medics, surgeons and combat personnel over the last several years. Despite great initial success in hemorrhage control, neither is considered an ideal agent. Each has drawbacks that will be discussed and need to be reconciled in order to meet the ideal requirements for military use. In addition, improvements in tourniquet design and usage recommendations have the potential to slow or stop hemorrhage and prolong life until definitive surgical intervention can be performed provided the tourniquet is applied properly.

One important aspect of hemorrhage control is a procedure referred to as damage control, the process of stabilizing the physiological processes of a casualty before evacuation procedures are commenced. The performance improvement program within the JTTS aided in the identification of this issue and pushed for the development of new procedures and training to enhance medical care for wounded personnel. In one illustration, combat personnel have adjusted medical tactics from the classic ABCs (Airway, Breathing, and Circulation) taught to civilians to CBA, a complete reversal of priority.

As the nature of the majority of combat injuries changes, the tools and procedures to care for these injuries must adapt as well and be made available for medics to effectively intervene. Advanced hemostatic products combined with improved damage control procedures can greatly enhance a patient's chance of survival and ability to achieve a functional recovery.

This section will discuss the development and implementation of damage control procedures and how it has served to prolong life in a combat scenario. Damage control has become more successful with the development and modification of seven hemostatic agents as well as improvements to tourniquet design and application. Each will be described with respect to success in the prevention of exsanguination, associated drawbacks, and the current or prospective use by military forces in hostile environments.

**Damage Control**

Recent data suggests that approximately 50-70% of battlefield injuries[15] are likely to be in the extremities, where the utilization of damage control procedures has been shown to increase survival rates and enable more casualties to achieve a fully functional recovery. Damage Control is a term used to describe the importance of stabilizing the physiological processes of a casualty before evacuation procedures are commenced. It was developed at U.S. urban trauma centers to prevent death in victims who suffered from massive hemorrhaging since taking time to perform definitive surgery immediately often resulted in a "fully repaired but dead patient."[16] Damage control consists of an abbreviated priority of procedures to "halt the downward spiral associated with the lethal triad of acidosis, hypothermia and coagulopathy, which often develops in the catastrophically injured."[17]

The focus of damage control is to stop bleeding and contamination through the application of standard or hemostatic dressings and the application of a tourniquet when appropriate. In addition, plastic tubes or vascular shunts may be inserted to control bleeding from disrupted vessels or restore blood flow where needed. Vascular shunts work like a quick fix to a broken garden hose. Damage control continues with the prevention of the lethal triad and

may include the performance of rapid external fixation or the splinting of extremity injuries, as well as transport to a higher echelon of care as soon as possible.[18]

Damage control, when applied to extremity vascular injuries is defined as the control of hemorrhage, rapid restoration of blood flow to an ischemic limb, and prevention of compartment syndrome, the result of swelling and compression of the nerves and blood vessels between layers of fascia tissue. In essence, if a casualty has suffered multiple injuries, limb salvage may not be a priority as physiologic stability is the primary focus to sustain life. The physiologic stability of a patient is paramount and once this state has been accomplished, transport by the most efficient means available must be conducted to ensure the patient gets to the right place at the right time.

Definitive surgery is not performed until stable physiological processes have been restored, the casualty has been evacuated to a medical treatment facility, and all injuries are reexamined. In basic terminology, stabilize and ship must be the focus of effort of medical personnel in combat operations to enable definitive surgery to take place at the next higher echelon of care whenever possible, ideally in a level V[19] facility back in the United States.

**Hemostatic Agents**

As the leading cause of preventable death, the preclusion of exsanguination from extremity wounds is critical to improve survival rates of severely injured patients and preserve more functional limbs upon recovery. As a result, medical intervention during casualty care while under fire is directed toward the arrestment of life-threatening bleeding as quickly as possible. Arterial bleeding and that of other major vessels can lead to hemorrhagic shock and exsanguination quickly, often before medical assistance arrives. Therefore, it is imperative that hemostatic agents and tourniquets have self-application capabilities.

Historically, approximately 20% of combat casualties were killed in action (KIA).[20] Of these casualties, 50% were due to exsanguination, 36% were a result of neurological trauma, while the remaining 14% were a result of devastating multiple injuries.[21] Data from the Vietnam War shows that roughly 38% of soldiers designated as KIA were caused by exsanguination with a hemorrhage source that could have been arrested and controlled while in the field.[22] More recently, the severity of torso injuries have decreased due to use of body armor and limbs remain the most common site of battlefield wounds.

Hemorrhage from a limb can be controlled with compression procedures and effective dressings much more easily than bleeding from within the torso, which may not be accessible.[23] Throughout OIF/OEF, the majority of trauma casualties that reach treatment facilities but die of wounds after surgery are a result of exsanguination and therefore it remains the leading cause of late death due to complications.[24]

Seven new hemorrhage control products have been tested by medics and surgeons over the last several years; QuikClot, HemCon, QuikClot Combat Gauze, HemCon ChitoFlex, Self-Expanding Hemostatic Polymer (SEHP), Dry Fibrin Sealant Dressing, and three modifications of Rapid Deployment Hemostat (RDH-1, RDH-2, and RDH-3). The first five appear promising; however, only the first four have been approved by the Food and Drug Administration (FDA). The first three have been approved for use by U.S. military forces. As these products are relatively new, there is still concern with the lack of current data and therefore the possibility of unknown detrimental side effects. The key to finding ideal hemostatic products is that they should meet the following criteria:[25]

1. Stop large-vessel arterial and venous bleeding within two minutes of application, even when applied to an actively bleeding site through a pool of blood, a likely field scenario.
2. Effective in areas not suitable for the application of a tourniquet, such as the groin or axilla.
3. Ready to use, with no requirement for mixing or preparation.
4. Simple to apply by the wounded individual, a buddy, or a medic with minimal training required.
5. Lightweight and durable.
6. Stable at room temperature as well as in extreme ambient temperatures.
7. Safe to use, posing no risk of either injury to the surrounding tissue or of bacterial or viral transmission.
8. Inexpensive.

This last requirement is particularly important in the military as cost considerations are critical when decisions are made to field these products to thousands of troops.

QuikClot, HemCon, QuikClot Combat Gauze, HemCon ChitoFlex and SEHP are the five hemostatic agents that show the most potential, and the first three have been deployed to both Iraq and Afghanistan; however, there is still much debate as each of the hemostatic agents tested thus far has drawbacks. The two most promising hemostatic agents, suitable for military use are QuikClot and HemCon. Members of the Uniformed Services University developed a complex groin injury model in swine to test new hemostatic dressings. The model simulated battlefield injuries by making the wound too high (groin) for successful tourniquet application and combined lethal arterial, venous, and soft-tissue injuries.[26] The control group used no dressing

and resulted in a mortality rate of 83%, while standard dressings reduced mortality to 33.4%. The addition of QuikClot (3.5 oz) applied five minutes after injury decreased mortality to 0% and demonstrated the lowest volume of blood loss. The exothermic reaction increased wound temperature for 30-60 seconds with maximum temperatures 42-44 degrees Celsius.[27] HemCon did not show an overall reduction in blood loss or mortality; however, this was due to inconsistent effectiveness in the dressings.[28] The dressing was extremely effective in improving hemostasis and survival in five cases, but failed completely in the other two. HemCon produced no side effects. Both agents have been approved by the FDA, are relatively inexpensive and suitable for use on battlefield. HemCon Combat Gauze has also been approved by the FDA and has recently been deployed by U.S. and Canadian Forces. HemCon ChitoFlex is a modification to HemCon that has been FDA-approved but not widely distributed yet. Finally, SEHP is the most recently developed hemostat and requires further studies to be conducted before it receives approval from either the FDA or for military use.

**QuikClot** is a granular zeolite mineral that is composed of oxides of silicon, aluminum, sodium, magnesium and quartz.[29] It is manufactured in a granular, powdered form with 1% residual moisture.[30] The FDA approved its use for clinical application in May 2002 and it appears to be effective, relatively inexpensive ($10 per dressing), easy to manufacture, extremely durable and easy to use.[31] QuikClot acts as a molecular sieve as water is absorbed from the blood and concentrates the platelets and clotting factors to promote rapid clot formation. The resulting exothermic reaction is a physical process and the amount of heat generated depends upon the ratio of zeolite to water.[32] This hemostatic product effectively reduces blood loss and increases survivability when used on low-pressure, high-flow venous injuries; however, it cannot be described as an ideal hemostat.[33]

Five drawbacks have been discovered thus far with the use of QuikClot. First, there is a risk of thermal injury to tissue due to the exothermic reaction that occurs during the clotting process. Second, responsive patients have consistently reported mild to severe pain associated with the heat generated upon application. Third, the effective use of this agent requires additional training in regards to appropriate application due to the risk of thermal injury to tissue, and therefore should be used only by properly trained care providers. Inappropriate application without removing excess fluid could cause severe thermal injury to internal organs in the vicinity of the wound. Fourth, a second procedure is currently required to remove the granules of QuikClot upon definitive surgery. This procedure requires further debridement of the wound to ensure that all of the hemostatic material is removed to prevent the possibility of long-term complications.[34] The final drawback is that it appears to be ineffective in cases where the patient is hemodiluted, coagulopathic, and moribund prior to the application of QuikClot and therefore may be useful in responsive patients only.[35]

There has been a great deal of discussion in regards to the amount of tissue injury that is associated with heat produced by the exothermic reaction of QuikClot powder in blood. Researchers have recorded maximum temperatures of 68-140 degrees Celsius during experiments.[36] The amount of heat generated during the reaction is directly related to the amount of blood and fluid in the wound at the time of QuikClot application. A relatively low blood flow within the wound resulted in a mild elevation in wound temperature with no associated tissue injury reported. As the amount of blood present increased, the maximum wound temperature upon application of the hemostatic product increased as well. Injuries with a high venous blood flow experienced a severe exothermic reaction and associated deep thermal injury. The zeolite hemostat is currently being modified to decrease the exothermic reaction; however, with the

current formula, QuikClot should be used with a clear understanding of potential risks, benefits and the need for adequate training.[37]

The Uniformed Services University assembled a panel to review and advise the U.S. Marine Corps on the feasibility of QuikClot in February 2003. Two main concerns were the possible consequences of the exothermic reaction and the extent of training required to use it properly. The panel recommended the use of QuikClot to control hemorrhage unresponsive to standard therapy and reasoned that the potential for tissue damage is offset by the opportunity to save a life in an otherwise uncontrolled external hemorrhage situation.[38] Additionally, detailed training requirements were developed and implemented for military and medical personnel on its proper use. The U.S. Marine Corps has incorporated QuikClot into individual first aid kits and added specific training on its proper usage, while the Army decided to limit its distribution to selected medical care providers.[39] More than 50,000 dressings have been deployed with units in both Iraq and Afghanistan.[40]

QuikClot was disseminated for use by U.S. military personnel very quickly once the initial testing of the zeolite hemostat had begun. Within just a few months it was being utilized in combat situations by special operations units in Afghanistan.[41] With very little data on possible long term effects of the zeolite hemostat, reports of the use of QuikClot to control hemorrhage within body cavities as well as extremity wounds are now appearing, while studies and research strive to gain a more comprehensive understanding of the possible thermal effects to cavity organs as a result of its exothermic qualities.[42] Thus far, 103 documented cases of the application of QuikClot indicate 100% efficacy in responsive patients and cause mild to severe pain due to the exothermic reaction in 25% of the cases.[43] QuikClot failed to control bleeding once the patient reached a hemodiluted, coagulopathic, and moribund state. In addition, four

complications have been documented. Three of the complications were burn cases that required further care, one required skin grafting. The fourth complication reported was caused by scar formation that resulted from a foreign body reaction after a QuikClot granule was left in the vicinity of the wound. The patient required additional surgery to remove the QuikClot granule and surrounding scar tissue.[44] No further complications have been documented.

Canadian and British Forces have incorporated QuikClot to some extent and distributed it to their forces as well. The British recommend its use to control low-pressure bleeding from an unidentified source.[45] Canada has great concerns over the exothermic properties and requirement for a debridement procedure of QuikClot and has begun to integrate a hemostat called **QuikClot Combat Gauze**. The combat gauze is a bandage composed of a clay mineral, layered silicate material that accelerates the formation of blood clots.[46] It has demonstrated to be successful in the packing of large, open wounds and decreases the speed with which the casualty loses blood. Canada has largely replaced QuikClot as the Combat Gauze has the advantages of QuikClot without the exothermic reaction caused from zeolite.[47] U.S. Forces have recently begun to use QuikClot Combat Gauze as well.

The other promising hemostat that is currently being used in both Iraq and Afghanistan is **HemCon**, a proprietary bandage impregnated with a poly-N-acetyl glucosamine-base. This chitin-based hemostatic agent promotes hemostasis through the ionic attraction of red blood cells into the dressing, causing bonding with the injured tissue surface.[48] It significantly increases survivability through the reduction of both blood loss and resuscitation fluid requirements. It has proven its effectiveness in challenging severe venous bleeding and somewhat effective in mixed and high pressure arterial hemorrhage. HemCon was approved by the FDA in November 2002.[49]

HemCon has no known harmful side effects, is easy to use, requires minimal additional training, and no special storage requirements; however, it does come with four drawbacks. It is slow to manufacture and costs approximately $100 per dressing. More importantly, the effectiveness of the dressings has been found to vary among batches. In one experiment, HemCon was effective in five of seven cases and failed completely in the remaining two. [50] HemCon seems be most effective in high-pressure bleeding scenarios from an identifiable source.[51] Finally, HemCon works extremely well on planar surfaces but the stiff dressing does not conform well to deep, narrow wounds or those of irregular shape without additional cutting of the bandage.

On October 1, 2007, the U.S. Army added the HemCon dressing as a standard item in the Improved First Aid Kit issued to deploying soldiers.[52] It is currently the most expensive dressing being used by deployed U.S. forces. British forces have incorporated the HemCon dressing into their medical inventory; however, Canadian forces are currently switching from the HemCon dressing to the QuikClot Combat gauze, which has demonstrated potentially greater efficacy in animal models.[53]

Two modifications should make HemCon a more useful hemostatic dressing for military use. Research is currently being done to correct the variability amongst dressings. Also, a second modification has been incorporated to make the dressing more pliable. This new, more flexible bandage is called **ChitoFlex**. It is made of the same chitin-based substance as HemCon with similar hemorrhage control properties and is designed to be packed into a wound track to control bleeding. It may prove to be well-suited for the control of severe bleeding from small penetrating injuries such as those resulting from small arms fire or shrapnel without the

exothermic reaction produced by the application of QuikClot.[54] Like HemCon, ChitoFlex has no known side effects. It has been approved by the FDA but has not been widely distributed yet.[55]

Several other hemostatic bandages are undergoing testing and modification. **Dry Fibrin Sealant Dressing** approaches ideal from a functional standpoint as it has proven effective in decreasing blood loss and increasing survival in low-pressure, high-flow bleeding; however it has four drawbacks.[56] The military has concerns about its durability when not handled carefully, especially in combat situations. It is expensive and runs approximately $500-1000 per dressing. It is not FDA-approved and is not currently being manufactured.[57]

**RDH** has undergone two modifications thus far. Both RDH-1 and RDH-2 were ineffective in swine model experiments. In RDH-3, the active ingredient was tripled and it was effective in reducing blood loss and increasing survival; however, the tests were conducted under greatly reduced flow conditions and complex surgical procedures were involved. Therefore, it has yet to convincingly demonstrate the ability to provide hemostasis under field relevant conditions for treatment of low-pressure, high-flow venous bleeding. It produces no reported harmful side effects, but currently costs $300 per dressing.[58]

A relatively new hemostatic product that may be added to the medical inventory is a **self-expanding hemostatic polymer (SEHP)**. It exerts a mechanical effect on the wound cavity to tamponade an active hemorrhage.[59] SEHP may present an optimal hemostatic method for both military and civilian applications. It controls bleeding by two mechanisms; blood absorption and a biochemical effect. The absorption of blood into SEHP causes rapid swelling and tamponade directly on the surface of the wound, resulting in pressure being uniformly applied. The biochemical effect is demonstrated as only the aqueous component of the blood is absorbed into the polymer, enabling the platelets and coagulation factors to concentrate, thereby accelerating

the clotting process.[60] The combination of these two factors stops the bleeding and seals the wound, without affecting blood flow to the remainder of the limb, and without requiring an individual to exert direct pressure on the wound. SEHP appears to be a novel, lightweight, portable dressing that can control bleeding with no adverse effects. The polymer is contained in a nylon bag that stretches as the polymer expands. It can be applied and removed easily as the nylon prevents adhesion between the polymer and the wound.[61] With the characteristics of an adaptable plug, SEHP can be applied in a set-and-forget fashion with no need for compression.[62] SEHP does not contain zeolite, the product that causes the exothermic reaction in QuikClot. Subsequently, there is no associated exothermic reaction or other side effects and it is not expensive. SEHP is expected to receive FDA approval upon further testing against HemCon, QuikClot, and other hemostatic agents. If tests are successful, SEHP may also be approved for use by military forces in tactical situations.

As a result of the considerable debate to determine which of these hemostatic agents is best for use in combat injuries, three conferences have been held in regards to the issues surrounding hemorrhage control. The outcome was a general agreement stating that the ideal hemostatic dressing is not yet available.[63] One issue is that the blast and projectiles created from the detonation of an improvised explosive device (IED) create wounds that are irregular in depth and geometry. Therefore, a "one-size-fits-all" approach may not be appropriate as injury type, severity, training requirements, and potential harmful effects must be taken into account.[64] QuikClot has demonstrated to be an effective hemorrhage control treatment in the care of deep, jagged wounds, whereas HemCon appears to be more appropriate for application on an even surface.[65] Neither agent is ultimately superior to the other; however, they are complementary in

their uses as hemostatic agents. Further research must be completed to achieve comprehensive results.

The results of the three conferences have been analyzed by the Committee on TCCC. The committee contains members from all military services, the Surgeon General of the United States, and civilian trauma experts. Conclusions have been difficult to draw for two reasons. Hemostatic agents are a relatively new development and information is limited as neither QuikClot nor HemCon has been used in a large clinical trial of trauma patients. In addition, as research continues, modifications to QuikClot and HemCon, as well as new hemostatic agents are continuously being developed. QuikClot Combat Gauze, HemCon ChitoFlex, and SEHP are three encouraging examples. Currently, the committee recommends that both QuikClot and HemCon dressings be deployed by all military services. Each bleeding wound should be treated with standard care first (pressure dressings, tourniquets, etc). If standard treatment is not sufficient, HemCon should be the first advanced hemostatic dressing applied in situations with high-pressure, high-flow bleeding. If HemCon is not available or has failed, QuikClot should be used as a last resort in a life-threatening situation. Excess blood and fluid should be removed prior to application to minimize potential thermal injury to surrounding tissue.[66] The recommendation to apply HemCon prior to using QuikClot was due to several reasons. HemCon has no known adverse effects even though it has shown to be a less effective hemostatic agent, thus far making it a potentially safer alternative to QuikClot. In addition, the powder form of QuikClot can be difficult to administer properly on the battlefield, especially at night due to decreased visibility and consideration that must be given to light discipline.[67]

The ideal hemostatic agent needs to be effective, easy to use, safe, and durable. Its application must serve to benefit most hemorrhage-type combat injuries whether they are life-

threatening or not, and enable easy application to include self-application by the injured combatant. Further military considerations must be taken into account as well. The benefit of an individual life saved balanced against the optimal choice for the largest number of personnel is not always the same. The ideal agent needs to serve both to be practical for military implementation. Unique combat conditions, logistical constraints, and training issues also influence decisions. Hemostatic agents will not serve as a substitute for standard treatments of compression and tourniquet use as the application of QuikClot without the implementation of standard damage control procedures may not be sufficient to arrest the bleeding and prevent exsanguination.[68]

Much more data must be collected and analyzed with further studies conducted to consider the long term effects, but for now, hemostatic agents appear to be controlling hemorrhage situations and assisting with life-saving procedures. The KIA rate amongst U.S. servicemembers, wounded as a result of combat action in Iraq started at 20% in 2003 and has been reduced to an overall 9.9% in Iraq and 12.3% in Afghanistan as of March 16, 2010.[69]

**Tourniquets**

Hemostatic bandages are just one source of hemorrhage control that requires improvement. Various versions of the tourniquet have been used throughout history, and are known to have been used as far back as the Greeks and Romans. The liberal use of tourniquets has always been a very controversial topic. Surgeons of previous conflicts have valid complaints when they claim that they have witnessed casualties lose a limb or suffer neurovascular injury as a result of prolonged application of an improvised tourniquet. One aspect that is rarely mentioned is that these surgeons did not see the casualties who bled to death on the battlefield in

desperate need of a tourniquet to prevent exsanguination.[70] Recent case studies present no evidence to support that tourniquet use on the battlefield has resulted in either increased limb loss or permanent disability.[71]

There are several complications associated with the inappropriate use of a tourniquet in regards to hemorrhage control. Common failures include application with insufficient pressure to arrest blood flow, excessive pressure resulting in skin damage and other complications, or failure to properly document and alert medical staff of their presence. A tourniquet applied incorrectly can result in an increase of blood flow from an extremity wound due to the occlusion of venous outflow in combination with the inadequate occlusion of arterial inflow. When this occurs, early exsanguination is the most likely result; therefore, proper training with emphasis on total arterial occlusion is crucial.[72] Prolonged use (defined as greater than two hours) or excessive pressure risks injury to the underlying muscle and nerve tissue as well as limb loss due to the byproducts of ischemia, distal to the site of application.[73] The longer a tourniquet remains in place without definitive surgery, the greater the chance of complication; however, rapid evacuation as well as early and aggressive operative intervention has increased the success of tourniquet use.

Tourniquet application is a simple, fast, and cheap way to control arterial flow in life-threatening situations; however, several considerations should be taken into account. Tourniquets should be applied with the lowest effective pressure to arrest hemorrhage and minimize subsequent ischemic complications. Wider or side-by-side tourniquets may be used to increase the effectiveness and minimize damage to underlying tissue. Even with minimal effective pressure applied, a tourniquet may cause significant pain and should be managed with intravenous or intramuscular pain medication. If applied to a hypotensive patient prior to

resuscitation, less pressure is required to arrest arterial hemorrhage; however, once resuscitation is initiated, systolic pressure increases and bleed-through may occur. A tourniquet must be monitored continuously and tightened periodically once resuscitation efforts have been implemented to prevent bleed-through.[74] It should also be properly labeled with the time it was applied and medical personnel need to be informed of its presence.[75] Finally, clothing should not be left between the tourniquet and underlying skin as it may cause slippage, thereby reducing its efficiency.

The ideal tourniquet should have the following desired properties:[76]

1. Achieve complete occlusion of arterial blood flow to the lower or upper limb.
2. Allow for rapid application under tactical conditions, including darkness with the option to self-apply with one hand or to a trapped limb.
3. Cause minimal tissue necrosis and pain as well as be light, portable, compact, removable, and inexpensive.
4. Durable enough to withstand battlefield conditions.
5. Tactically appropriate in color.
6. Easy to manufacture with few or no mechanical parts.
7. Easy enough for the average soldier to learn to apply with confidence.

There are two current tourniquet models fielded by the U.S. military that meet these requirements; the Combat Application Tourniquet (CAT) and the Pneumatic Emergency Medical Tourniquet (EMT). The CAT is a wide, windlass-like tourniquet with a strap/ratchet design. It effectively occludes arterial blood flow, is relatively easy to use and inexpensive. The newly developed CAT has the capability of self-application as well.[77] A seemingly insignificant change to tourniquet use, this simple advance enables an injured combatant to arrest the bleeding

himself. A medic may be unable to get to the casualty due to hostile fire or may be engaged in the provision of treatment to other casualties as well. The CAT is limited by its lack of fine adjustment capability. Additionally, it can often be applied too loosely to occlude arterial flow or too tightly, causing significant pain. It is currently the best prehospital tourniquet and has become a component of the Improved First Aid Kit issued to all deployed soldiers. The EMT is more effective and causes less pain than the CAT, but it is more expensive, lacks durability, requires more training, and is too bulky for field issue. Currently, it is used in medical evacuation vehicles and treatment facilities.

The TCCC recommends tourniquet use in situations involving uncontrolled bleeding, limb amputation or when a patient is in shock with a contributing exsanguinating wound. It should be used to control life-threatening bleeding when continuous direct pressure and other hemostatic strategies are not effective or feasible, or during transport when extremity hemorrhage may be difficult to assess or direct pressure is hard to maintain. A tourniquet should be applied when safety concerns at the point of injury preclude patient evaluation, evacuation, or treatment. Tourniquet use is appropriate when under fire, in darkness, during mass casualty situations, or to deal with multiple limb exsanguinations. In such cases, a casualty may be able to apply the CAT himself, thus limiting the exposure of comrades to further hostile fire until he is able to gain access to a covered position where treatment may continue to include the care of other possible non-life-threatening injuries.[78]

The proper use of tourniquets is even more important today as the use of body armor has reduced the occurrence of trauma to the torso region; therefore, a substantially greater percentage of combatants survive and are able to present to medical treatment facilities with vascular injuries to the extremities to receive definitive surgical care.[79] Many of the soldiers who do

perish in combat succumb to their injuries rapidly and before evacuation to a combat hospital or aid station can be accomplished. The majority of them succumb to the hemorrhage of an extremity wound and their only chance of survival rests with available medics and combat personnel themselves.[80]

Despite the ongoing controversy with regards to possible complications and failures due to inappropriate application, improved tourniquet design and usage techniques may be the most important factors in improving survival in casualties sustained during OIF/OEF by attaining rapid hemorrhage control and limiting the risk of shock. Therefore, it makes more sense to improve the training of military and medical personnel than abandon the use of such a critical life-saving device. Success depends on proper training and rapid evacuation to a surgical facility.

**Conclusion to Hemorrhage Control**

Improvements in hemorrhage control procedures and equipment are a top priority among trauma care specialists. Current analysis shows that trends in warfare continue to move rapidly towards nonlinear battlefields and urban conflicts, and is further complicated by terrorist activities and guerrilla warfare versus the traditional combat that took place in past conflicts.[81] Conventional warfare will most likely be brief due to the superiority of U.S. and coalition military forces, but the post war period will continue to be characterized by prolonged conflicts in urban areas or hostile terrain between an ill-defined enemy and small, rapidly mobile U.S. and coalition combat units.

Current technology enables initial medical treatment to occur closer to the point of injury than in previous conflicts, but prolonged evacuation and extended distances to level III or higher

facilities often result in longer time until definitive surgery is performed. This extended timeline makes the role of combat prehospital medical care, especially developments in hemorrhage control even more critical.

## Joint Theater Trauma System

Effective hemorrhage control is a critical first step towards increasing the survivability of casualties on the battlefield. Once the bleeding is controlled; however, many soldiers will still succumb to their wounds without further medical treatment within sixty to ninety minutes. This timeframe is often referred to as the "golden hour"[82] and the JTTS has made considerable improvements to ensure that the most critically injured receive care as quickly as possible.

As recent combat operations have shifted to nonlinear wars or counterinsurgency operations, the use of smaller and more widely dispersed units resulted in the need for independent mobile surgical teams. The Forward Resuscitative Surgical Suite (FRSS) teams used by the Navy/Marine Corps and the Army's Forward Surgical Teams (FST) fulfilled this need with the ability to travel great distances to remain co-located with ground combat units. The FRSS / FST teams maintain optimum trauma care capabilities and a central means of organization, communication and evacuation to medical treatment facilities from remote, often austere locations. A large, centralized system was required to maintain overall organization of these forward medical teams as well as provide efficient transport and trauma care for casualties over the increased distances within which combat operations were taking place. The U.S. Army Medical Department took the lead as part of a joint effort to develop and deploy the world's largest and most complex trauma system.[83]

The JTTS fulfilled this organizational requirement, was initiated in May 2004 and formally implemented in November 2004. A trauma system is an arrangement of available resources coordinated for the effective delivery of emergency healthcare services in a designated geographical region.[84] It was established to provide the ability to track, trend, and report performance processes within the combat theaters of Iraq and Afghanistan. The JTTS was based on an already existing civilian trauma system with some adaptations that were necessary to work within the realities of combat. The JTTS aims to get the right patient to the right place at the right time.[85] It has accomplished this goal through the implementation of medical advances, evacuation and information management procedures. The implementation of the JTTS provides numerous opportunities to improve the chances of survival of soldiers wounded on the battlefield.

**Structure**

The JTTS is structured with five echelons of military, medical care. Level I Echelon of Care occurs at the small unit level, begins with Self-Aid/Buddy care and includes treatment by a battalion aid station, combat lifesavers, or other elements of an area support medical battalion. The goal of Level I care is to provide minimal treatment and return to duty or to stabilize the casualty and provide for further evacuation.[86] Level II often includes an Army FST or Navy/Marine Corps FRSS. Level II is organic to brigades, divisions and area support battalions. Casualties are examined and evaluated to determine treatment and evacuation precedence. Level II is also the first place that whole blood is readily available. Patients held here are expected to return to duty within 72 hours.[87] Level III facilities include the Army combat support hospitals, Navy ships and Air Force theater hospitals. These treatment centers are fixed medical facilities

that provide specialty-based "hospital" care such as resuscitation, initial wound surgery, and post-operative treatment. Patients may be returned to duty or stabilized for further evacuation. Level IV is a general hospital that provides definitive surgical care outside the combat zone but within the theater of operations. The goal is to rehabilitate and return to duty or reevaluate and treat patients for transport back to the United States. Landstuhl Regional Medical Center (LRMC) is the Level IV facility for operations in both Iraq and Afghanistan.[88] The highest care facility is the Level V, located within military, medical centers in the continental United States. It is designated for long-term recovery, rehabilitation and support for those not expected to return to duty. It is the most definitive care available within the Health Services Support System and includes medical facilities such as the National Naval Medical Center, located in Bethesda, Maryland.[89]

The JTTS sends teams to collect data and evaluate trauma system component issues throughout all five levels of care to identify and develop methods, techniques and procedures to improve medical care. Data is collected using the JTTR as well as interview and survey methods to evaluate logistical aspects of the system. Each team is composed of a trauma surgeon and six trauma nurse coordinators. Together, they implement the JTTR, conduct web-based feedback on casualties, perform regional morbidity and mortality conferences, have an ongoing performance improvement program, publish clinical practice guidelines and flight standard operating procedures, perform medical flight reviews and evacuation procedures, assist with the placement of surgical teams in optimal locations, develop the process where combat casualty research can be performed, and develop prevention strategies.[90]

**Joint Theater Trauma Registry**

The JTTS is responsible for the review and maintenance of the JTTR, a database that records critical medical treatment information on patients injured within a theater of combat operations and treated at U.S. medical treatment facilities. The registry is formatted along the principles of the civilian trauma registry. Entries follow the casualty from the initial point of entry through subsequent echelons of care, and terminate at a level V medical treatment facility in the United States.[91] The JTTR utilizes a concise form to capture demographic, mechanistic, physiologic, diagnostic, therapeutic, and outcome data along with a physical examination of each patient.[92] It acts as a primary collection source for performance improvement and allows the consolidated and current capture of injury data to be examined through a research database providing access to commanders, researchers, combat personnel and physicians.[93]

As a result of this consolidated registry, U.S. and coalition forces are able to evaluate data with the ability to react to changing tactics and injury patterns to produce new interventions. The JTTR has made immense improvements and currently contains data on more than 80% of casualties from OIF/OEF, up from 10% initially.[94]

**Performance Improvement**

The performance improvement program mentioned above was developed and implemented in 2007. This program serves as an avenue to identify areas within the JTTS that require advancement, execute performance improvement initiatives across the continuum of care, and monitor the ensuing outcomes of these advancements and initiatives.[95] It researches and revises training programs to ensure personnel receive the most current training and procedures

available. Trauma leaders at LRMC report performance issues to the JTTS weekly in efforts to assist in the improvement of medical care within theater.

The performance improvement program recently identified information management as inadequate. Casualties were often transported to higher echelons of care without proper documentation of previous evaluation and treatment, especially during high tempo operations, communication failures, high casualty load and hostile battlefield scenarios. The JTTR incorporated a standard sheet to be filled out and passed electronically within the JTTS. In the absence of a computer or in cases where initial medical evaluation and treatment is carried out in a hostile environment, it is recommended that prehospital medical personnel document information with permanent marker on the patient's skin so that it may be relayed to the next caregiver and properly inputted into the JTTR at the first possible opportunity.[96] Additionally, portable computer storage drives should be located with evacuation teams to allow for digital transfer of X-rays, pictures, trauma history, and physical E-Forms.[97] These thumb drives should be attached to the casualty via dogtags. It was critical to develop a standardization of practice with the flexibility to adapt to a variety of work and combat environments. The use of permanent marker and the follow-on use of thumb drives provided standard methods to relay critical casualty information to higher echelons of care when internet access and other communications abilities had failed or were otherwise inaccessible.

The performance improvement program has also provided significant data to influence improvements in personal protective equipment. In previous conflicts, torso injuries carried a high mortality rate and many casualties did not survive long enough to receive surgical treatment.[98] Current insurgent tactics and ambushes have caused a change in wounding patterns as IEDs cause multiple fragment injuries and cause approximately 87% of casualties in Iraq and

Afghanistan.[99] Personal protective gear has evolved and the use of body armor has decreased the number of casualties with severe chest and abdomen injuries.[100] One study of casualties in OIF showed that 14% of U.S. casualties versus 27% of Iraqi casualties suffered severe injury to the chest or abdominal regions.[101] Since Iraqi soldiers did not wear body armor, this study demonstrates that armored body protection has reduced the traumatic impact of high velocity munitions. Body armor does not affect injuries to the extremities; however, many casualties that would have otherwise succumbed to severe torso injuries survive to present with injuries to the extremities.

**Evacuation**

The JTTS constantly monitors and makes adjustments to standard flight operating procedures and performs medical flight reviews. They ensure that FRSS / FST teams as well as evacuation assets are optimally placed throughout the theater to ensure casualties may be evacuated not only quickly, but also by the safest routing available.

Advanced air evacuation equipment and procedures have become critical to increase the survivability of military personnel and are therefore influenced by the performance improvement program. The emplacement of IEDs makes roads within Iraq unsafe for ground travel, and Afghanistan has no reliable road system. Furthermore, the combination of urban warfare operations in Iraq and extreme distances that must be travelled throughout Afghanistan makes ground evacuation a poor option in either country.[102]

The ability to evacuate casualties out of theater has improved immensely since Vietnam. Critical surgical care is often commenced within 1-4 hours of injury after evacuation to a level II or III medical facility. Casualties may find themselves in an intensive care unit in the United

States within 2-4 days. Current procedures under the JTTS require that patients not expected to return to duty within theater be stabilized and evacuated through level III and IV care to the United States for definitive surgery and rehabilitation.

The aeromedical evacuation system, developed in 1994, serves to expedite the transport of the critically wounded while providing the necessary equipment and personnel to sustain a flying intensive care unit. The most advanced system is the U.S. Air Force Critical Care Air Transport Team (CCATT) which consists of an "intensivist" with formal critical care fellowship training, a critical care nurse, and a respiratory therapist.[103] Each team maintains the capability to continue resuscitation and advance the care of casualties either on the ground or en route to the next higher echelon of care. Since September 2001, CCATT has completed more than 27,650 aeromedical evacuation sorties and transported more than 130,000 patients within the theaters of OIF/OEF.[104]

In addition to assessing the optimal placement for and routing of forward medical teams and air evacuation assets, medical equipment carried aboard various air assets is also developed and reviewed under the JTTS. The significant number of air evacuation operations that have been carried out during OIF/OEF has provided the opportunity to conduct extensive research to develop and evaluate new equipment to improve medical capabilities aboard evacuation assets. Medical equipment and procedures that work well in a stable and stationary environment are not always conducive to effective operation under the additional stresses that accompany flight. Stresses such as unexpected motion, changes in air pressure and the resulting expansion of gases, and high noise levels impede patient assessment and equipment stability and operation. Space to maintain necessary equipment and drugs is severely limited. Electromagnetic interference with aircraft navigation and operating equipment may be caused by medical equipment, and power

conversion requirements add a further challenge to the already stressful aviation environment.[105] Challenges to both personnel and logistics are critical and research continues in order to provide the most effective critical care possible during air transport and evacuation.

The decision and timeliness to move a patient is a challenge that must also balance the benefit of resources available at the next echelon against risks inherent in moving a critical patient with all the necessary tubes, lines, monitors and equipment. Care requirements such as the recognition and support of multiple organ failure and other complications are far more difficult to provide for while airborne than from within a stationary medical facility.[106] Therefore, the ability of the JTTS to track patients, monitor the availability of evacuation assets and keep up to date with resources available at each medical treatment facility assists in this decision-making process.

Methods to decrease the time from point of injury to surgical treatment require improvement but come with additional challenges in a combat situation. With the organization provided under the JTTS and airlift capabilities, casualties often present to a level II or III facility within several hours of injury and there is little that will improve evacuation times on the battlefield except well-planned and rehearsed evacuation routes, both on the ground and in the air.[107] This challenge heightens the importance of well-trained combat medics who travel forward with units to carry out damage control treatment not only during evacuation procedures but under fire, in the dark, within a confusing and hostile operating environment.

As the JTTS has become the standard of care on the battlefield, it has allowed researchers to identify and address multiple shortfalls. Improvements identified and pursued through the performance improvement program have effectively improved the JTTS, thereby increasing survivability of casualties in both Iraq and Afghanistan.

## Conclusion

Improved medical and technological advances have resulted in the lowest mortality rates in U.S. history.[108] In spite of this monumental achievement, statistics taken from the Vietnam War and compared to those thus far in OIF/OEF suggest that the casualty rates have not changed dramatically even with these new technological advances and updated procedures. It would be reasonable to assume that casualty rates should decline with the widespread use of body armor amongst U.S. and coalition combat personnel, which have shown a relative decrease in severe injury to the chest and abdominal regions. Improved hemorrhage control devices and increased focus on prehospital TCCC training provide additional contributing factors to enhance the survival rate amongst casualties. Furthermore, the implementation of the JTTS has served as the standard of organization and coordination through developments in research, techniques, training and procedures to ensure combat casualty care becomes increasingly more effective.

Additionally, there are technological advances that serve to increase survivability but demonstrate some degree of disparity between expected KIA and died of wound (DOW) rates. Two examples are the implementation of rapid evacuation to transport patients to medical treatment facilities to receive definitive surgery versus the increase in the destructive nature of weapon systems employed by our enemies. Rapid evacuation results in a greater percentage of casualties surviving initial injury to receive definitive surgery, thereby decreasing KIA rates. At the same time, DOW rates have risen as a greater percentage of the more severely injured casualties now die after rapid evacuation but before definitive surgery is completed.[109] The increased destructive power of IEDs and modern weapons systems has resulted in more severe injuries than those of past conflicts. Significant advancements in medical capabilities were

critical to prevent drastically increased casualty rates, particularly KIA due to the massive tissue destruction caused by the use of high-velocity explosives and munitions.

As we try to reduce DOW rates, it is tempting to compare current practice to historical data; however, the population used in various studies does not always coincide. Some studies take into account combatants and non-combatants alike and may include the entire populace within the vicinity of hostile operations, whereas other studies limit research to combatants only. Further discrepancies are noted as some studies limit research even further to combatants injured during combat operations or they may include non-hostile actions as well. As a result, statistics within each study must be closely evaluated and adapted to conform to a population suitable for the scenario for which the statistics are being applied.

Regardless of the populations incorporated to collect data, three major principles must be taken into account. The employment of high-velocity explosives and munitions has increased the lethality of weapon systems resulting in more severe injuries as well as a greater number of casualties due to a single hostile action or event. The increased destructive ability of these weapon systems can be offset to some degree by the development of advanced protective gear utilized by military forces that has allowed personnel to survive otherwise lethal injuries to the torso region. Improvements in hemorrhage control have further reduced the percentage of casualties that succumb to exsanguination and provide for early casualty stabilization. Finally, enhanced evacuation procedures limit the time from point of injury to arrival at a medical treatment facility.

Extremity injuries will continue to be seen with higher frequency as a result of rapid evacuation capabilities. The statistics for limb amputations will likely remain unchanged when compared with statistics from Vietnam since casualties have a greater chance of surviving the

initial attack and evacuation to a medical treatment facility.[110] Despite dramatic improvements in surgical techniques and the forward deployment of specialist care, the degree of tissue destruction due to high-velocity munitions has increased dramatically and over 90% of amputations still remain a result of initial severity of injury or traumatic amputation.[111]

Further data must be collected to confirm how these improvements have affected overall casualty rates, rate of survival, and rate of return to fully functional individuals. Early results demonstrate that these improvements are necessary and consistent in order for medical and military personnel to combat the employment of more destructive weapon systems and the changing tactics associated with conducting counterinsurgency operations.

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States. The National Naval Medical Center, located in Bethesda, MD is a level V facility.

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## APPENDIX A

### Acronyms

ABC - Airway, Breathing, Circulation

CAT - Combat Application Tourniquet

CBA - Circulation, Breathing, Airway

CCATT - Critical Care Air Transport Team

DOW - Died of Wounds

EMT - Pneumatic Emergency Medical Tourniquet

FDA - Food and Drug Administration

FRSS - Forward Resuscitative Surgical Suite team (Navy / Marine Corps)

FST - Forward Surgical Teams (Army)

IED - Improvised Explosive Device

JTTR - Joint Theater Trauma Registry

JTTS - Joint Theater Trauma System

KIA - Killed in Action

LRMC - Landstuhl Regional Medical Center, Germany

OEF - Operation Enduring Freedom

OIF - Operation Iraqi Freedom

RDH - Rapid Deployment Hemostat – 3 modifications (RDH-1, RDH-2, and RDH-3)

SEHP - Self-Expanding Hemostatic Polymer

TCCC - Tactical Combat Casualty Care

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