

# Advances in damage control resuscitation and surgery: implications on the organization of future military field forces

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Accepted for publication  
 Feb. 23, 2015

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DOI: 10.1503/cjs.001815

Medical support to deployed field forces is increasingly becoming a shared responsibility among allied nations. National military medical planners face several key challenges, including fiscal restraints, raised expectations of standards of care in the field and a shortage of appropriately trained specialists. Even so, medical services are now in high demand, and the availability of medical support may become the limiting factor that determines how and where combat units can deploy. The influence of medical factors on operational decisions is therefore leading to an increasing requirement for multinational medical solutions. Nations must agree on the common standards that govern the care of the wounded. These standards will always need to take into account increased public expectations regarding the quality of care. The purpose of this article is to both review North Atlantic Treaty Organization (NATO) policies that govern multinational medical missions and to discuss how recent scientific advances in prehospital battlefield care, damage control resuscitation and damage control surgery may inform how countries within NATO choose to organize and deploy their field forces in the future.

De plus en plus, la responsabilité du soutien médical offert aux forces militaires déployées sur le terrain devient partagée entre les nations alliées. Les planificateurs médicaux militaires nationaux font face à plusieurs défis importants, tels que restrictions budgétaires, attentes élevées au chapitre des normes de soin sur le terrain et pénurie de spécialistes dûment formés. Malgré cela, les services médicaux sont présentement en grande demande et leur disponibilité pourrait devenir le facteur limitatif susceptible de déterminer de quelle façon et en quels lieux les unités de combat peuvent se déployer. L'impact des facteurs médicaux sur les décisions opérationnelles requiert donc de plus en plus des solutions médicales multinationales. Les nations doivent s'entendre sur des normes communes qui régissent les soins à prodiguer aux blessés. Ces normes devront toujours tenir compte des attentes accrues du public en regard de la qualité des soins. Le but de cet article est de revoir les politiques de l'Organisation du Traité de l'Atlantique Nord (OTAN) qui régissent les missions médicales multinationales et de discuter de la façon dont les progrès scientifiques récents des soins pré-hospitaliers sur les champs de bataille et les techniques de réanimation et de chirurgie de sauvetage peuvent éclairer la façon dont les pays de l'OTAN décideront d'organiser et de déployer leurs forces sur le terrain à l'avenir.

**T**he mandate of the Canadian Armed Forces (CAF) is to protect Canada, defend North America in cooperation with the United States and contribute to international peace and security in partnership with allies from other countries.<sup>1</sup> In principle, medical support to any CAF mission remains a national responsibility. The Canadian Forces Health Services (CFHS) is responsible for providing full-spectrum, high-quality health services to Canada's military forces wherever they serve.<sup>2</sup> In practice, however, medical support to expeditionary forces is increasingly becoming a shared responsibility among allied nations.

National military medical planners face several key challenges, including fiscal restraints, raised expectations of standards of care in the field and a shortage of appropriately trained specialists.<sup>3</sup> Even so, medical services are now in high demand, and the availability of medical support may become the limiting factor that determines how and where combat units can deploy. The influence of medical factors on operational decisions is therefore leading to an increasing

requirement for multinational medical solutions. Collectively pooling medical resources has enabled Canada and its allies to generate military medical capabilities needed to support recent missions in Afghanistan and around the world. However, conducting multinational medical missions can be challenging.<sup>4</sup> Nations must agree on the common standards that govern the care of the wounded. These standards will always need to take into account increased public expectations regarding the quality of care.

Since its inception in 1949, the North Atlantic Treaty Organization (NATO) has been a cornerstone of Canadian defence and security policy.<sup>5</sup> The CAF have contributed to every NATO operation since its founding<sup>5</sup> and will likely continue to do so as part of the CAF mandate to contribute to international peace and security. The purpose of this paper is to both review NATO policies that govern multinational medical missions and to discuss how recent scientific advances in prehospital battlefield care, damage control resuscitation and damage control surgery (DCS) may inform how countries within NATO choose to organize and deploy their Field Forces in the future.

## THE NATO CONCEPT OF MEDICAL SUPPORT

### *Continuum of care*

NATO laid out its medical doctrine in its Allied Joint Publication 4–10(A), “Allied Joint Medical Doctrine.”<sup>6</sup> In this publication, NATO defined medical treatment facilities (MTFs) as the facilities where injured military members are treated throughout the entire continuum of care. These MTFs are designated a Role number to describe their functional capability to deliver a specific level of care. In NATO doctrine, it is implicit that higher-level Roles incorporate the functions of lower-level Roles. For example, a Role 2 MTF will routinely incorporate a primary care role, which is defined as a Role 1 function. The broad capabilities that may be expected at each level are described below.<sup>6</sup>

#### **Role 1**

Role 1 includes the provision of primary care, emergency treatment, resuscitation and stabilization, and preparation for transfer. Generally, Role 1 medical support is a national responsibility and it must be readily and easily available to all force personnel. Role 1 care is provided at the site or very close to the site of injury.

#### **Role 2**

A Role 2 MTF is a facility capable of receiving and triaging casualties and able to perform resuscitation and treatment of shock at a higher level than Role 1 facilities. Role 2 will routinely include DCS capabilities and may include a limited, short-term holding facility for casualties until evacuation can be arranged. The deployment of Role 2

MTFs is mission-dependent; the decision to deploy a Role 2 MTF may depend on the risk assessment, on geography and its effect on evacuation, or on the size of the deployed force. It is in light of these factors that NATO countries sometimes feel the need to increase the clinical capability of their Role 2 MTFs. Role 2 MTFs are now classified as Role 2 Basic and Role 2 Enhanced. A Role 2 Enhanced facility will have more “enhanced” surgical modules in order to provide commanders with a more robust capability if required.

#### **Role 3**

Major specialist facilities are available at the Role 3 level of care, including advanced diagnostic imaging, intensive care units, holding and nursing capabilities. Final sorting of casualties for transfer to Role 4 or return to duties will occur at Role 3 facilities.

#### **Role 4**

Role 4 facilities provide the full spectrum of definitive medical care that cannot be deployed to theatre or that is too time-consuming to be conducted in-theatre. This would normally include definitive care, specialist surgical and medical procedures, reconstructive surgery and rehabilitation. This care is highly specialized and comprehensive and is normally provided in the home country.

### *Timelines for care under NATO doctrine*

In its Allied Joint Medical Doctrine,<sup>6</sup> NATO also laid out its expectations regarding time-related constraints of medical care, which begin at the time of wounding. The time constraints have been termed the NATO “1-2-4 rule:”

- golden hour — MEDEVAC and advanced trauma care assets must reach the casualty within 1 hour of wounding,
- DCS — casualties who require urgent surgery should be under treatment in a facility staffed and equipped for this within 2 hours of wounding (usually done at a Role 2 MTF), and
- primary surgery — casualties should receive primary surgery directed at first repair of local damage from wounding not more than 4 hours after injury (usually performed in a Role 3 facility).

However, following extensive national engagement, the June 2011 meeting of the NATO Committee of the Chiefs of the Military Medical Services endorsed a NATO Life & Limb Saving Timeline to replace the “1-2-4” timeline. The new timeline is a “10-1-2” rule, which is described in the Allied Command Operations (ACO) Directive 83–1 on Medical Support to Operations:<sup>7</sup>

- 10 minutes — enhanced first aid (immediate life saving measures applied by personnel trained in Tactical Combat Casualty Care (TCCC); bleeding and airway control for severely injured casualties to be achieved within 10 minutes of wounding),

- 1 hour — damage control resuscitation (DCR; resuscitative measures initiated by emergency medical personnel within 1 hour of wounding), and
- 2 hours — DCS (depending on the specific and individual requirement, the aim is to be able to provide DCS within 1 hour but no later than 2 hours of wounding).

### Modular approach to multinational care

The need to have a facility capable of providing DCR within 1 hour of wounding and DCS within 1–2 hours of wounding has increased the demands for advanced medical and surgical support to NATO missions. To mitigate potential medical shortfalls, NATO has taken a multinational approach and a modular approach to providing military health care along the entire continuum of care, while on expeditionary operations.<sup>8</sup> The purpose of the modular approach is to allow coalitions to pool and share national medical capabilities and create multinational treatment facilities. To ensure that this modular approach is workable, standardization of modular components is required.

Seven core modules and 14 enhancing modules have been identified. The enhancing modules can be selected from the so-called “NATO medical toolbox.” “Enhancing” refers to an incremental increase in the level of care. Not all modules are needed for each mission; the need for any particular module will depend on a risk assessment, host nation support, climatic and epidemiological circumstances, planned duration, and geographic and environmental factors. A third group of modular components, the complementary contributions, also exists. A list of common modules is listed in Table 1.

**Table 1. Core, enhanced and complementary modules**

Core modules	Enhanced modules	Complementary modules
Emergency department care (DCR)	Primary surgery	Oxygen production
Initial surgery (DCS)	Imaging	Hyperbaric medicine
Diagnostic capabilities (laboratory)	CT scan	Frozen blood products
Patient holding (ward)	Ward	Animal care
Postoperative care (high dependency)	ICU	Physiotherapy
Command and control	Laboratory	Preventative medicine
Med supply	Pharmacy	Telemedicine
	Dental	Mortuary
	Mental health	CBRN
	Internal medicine	Subspecialist surgery
	Isolation	MRI
	Hospital management	
	Sterilization	
	Primary care	

CBRN = chemical, biological, radiological and nuclear warfare; CT = computed tomography; DCR = damage control resuscitation; DCS = damage control surgery; ICU = intensive care unit; MRI = magnetic resonance imaging.

### Casualty management strategies

#### Tactical Combat Casualty Care

While on expeditionary deployments, combat medical technicians provide enhanced first aid within 10 minutes of injury using the paradigm of TCCC,<sup>9</sup> which is a prehospital trauma approach designed to treat potentially preventable causes of death on the battlefield. However, TCCC acknowledges that application of these treatments may place the provider in jeopardy if performed at the wrong time and may affect the mission. As such, TCCC has 3 goals: treat the casualty, prevent additional casualties and complete the mission.<sup>10</sup> To achieve these 3 goals, TCCC classifies the tactical situation with respect to health care provision into 3 phases — care under fire, tactical field care and tactical evacuation — and permits only certain interventions to be performed during specific phases based on the danger to the provider and casualty.

During the care under fire phase, providers or casualties are permitted only to apply tourniquets to exsanguinating extremity hemorrhages. Once into the tactical field care phase, providers can treat acute airway obstruction with either a nasopharyngeal airway or a cricothyrotomy. They can treat tension pneumothoraces with needle decompression and treat open pneumothoraces with dressings. They are able to treat exsanguinating hemorrhage with tourniquets, wound packing, tranexamic acid administration, fluid administration and hypothermia-preventive measures. Providers can initiate treatment for penetrating eye injuries, splint fractures and administer antibiotics and pain medication. Choices for the tactical evacuation phase include land ambulance and rotary winged aircraft. There are data from the civilian literature to suggest that having rotary wing evacuation capability compared with only a land-based capability provides a survival benefit for trauma patients.<sup>11,12</sup> Furthermore, there is literature from recent conflicts in Iraq and Afghanistan suggesting that having physicians and enhanced resuscitation capabilities on helicopters improves the chances for survival in critically injured soldiers.<sup>13–15</sup>

#### Damage control resuscitation

Although DCR is not formally defined within NATO doctrine, the concept is now accepted throughout most NATO countries. Damage control resuscitation may be defined as a systematic approach to resuscitating critically injured trauma patients along the entire continuum of care; the target patients for DCR are the ones most at risk of traumatic coagulopathy and death.<sup>16</sup> The providers who start a DCR protocol are aiming to address the “lethal triad” immediately upon initiating treatment of the injured patient.

The “lethal triad” consists of hypothermia, coagulopathy and acidosis; these 3 factors are known to be predictive of mortality in adult trauma victims.<sup>16</sup> Hypothermia and acidosis have been shown to result in coagulopathy

and worsening shock, which further perpetuates the cycle.<sup>17</sup> Damage control resuscitation attempts to address these metabolic derangements early after injury in an effort to halt or ameliorate their consequences. The basic tenets of this approach include permissive hypotension, hemostatic resuscitation and hemorrhage control using a DCS approach.<sup>16,18</sup> Efforts to prevent hypothermia and rewarm the patients are initiated early and maintained throughout. Damage control resuscitation may not be required for most injured patients; its greatest utility may be with the 25% of trauma patients who present with early coagulopathy and who may have a mortality as high as 50%.<sup>19,20</sup>

Hypotensive resuscitation is a key tenet in DCR. In the prehospital setting, fluid administration is restricted by titrating its administration to a palpable radial pulse and maintenance of the motor and verbal Glasgow Coma Scale score (in the absence of traumatic brain injury). This approach is supported by 2 randomized controlled trials that showed that using a restrictive prehospital fluid resuscitation strategy was associated with decreased mortality in trauma patients presenting with shock.<sup>21,22</sup>

Upon arrival to an MTF, a hemostatic resuscitative approach may be adopted. This term suggests that blood and blood products, instead of crystalloid, may be used as primary resuscitation fluids to aggressively treat coagulopathy and to prevent the development of a worsening dilutional coagulopathy. Borgman and colleagues<sup>23</sup> retrospectively studied all patients who received massive transfusions at U.S. Combat Support Hospitals and found that patients who received a high ratio of plasma:packed red blood cell (PRBC) transfusions had a much lower mortality (19% v. 65%). Despite methodological issues with this study, hemostatic resuscitation using 1:1:1 ratios of plasma:platelets:PRBCs has been widely adopted, and retrospective studies have shown tremendous potential for such an approach.<sup>24–29</sup> A single centre pilot randomized controlled trial failed to show a survival benefit of this hemostatic resuscitation strategy.<sup>30</sup> However, a larger multicentred randomized controlled trial has just been completed, and the results are still pending.<sup>31</sup>

The administration of tranexamic acid (TXA) is another cornerstone in hemostatic resuscitation, as it also treats coagulopathy by targeting one of the underlying mechanisms in the development of trauma associated coagulopathy: fibrinolysis. The landmark CRASH-2 trial randomized 20 127 patients to receive TXA versus placebo. The study demonstrated a reduction in both all-cause mortality and death due to bleeding, without a significant increase in vascular occlusive events.<sup>32</sup> Tranexamic acid has also been shown to be effective in reducing mortality in the military setting.<sup>33</sup> Subgroup analyses have suggested that TXA is most effective when administered within 3 hours of injury.

As discussed previously, DCR begins early after injury, and occurs along the entire continuum of care. Because of potentially long evacuation times during military missions,

and because of the new NATO 10-1-2 timeline, there is an increasing push to provide advanced DCR interventions in the prehospital, Role 1 and tactical evacuation settings. This concept is now commonly referred to as remote DCR.<sup>34</sup> Limiting crystalloid infusion is easy to do in the prehospital setting. However, initiating a hemostatic resuscitation strategy in the prehospital setting may be challenging. Even so, advocates of remote DCR point out that there is evidence to suggest that prehospital administration of plasma may be beneficial.<sup>35</sup> The logistical challenges involved with deploying thawed plasma to the battlefield, however, have caused proponents of remote DCR to look for alternative solutions.

Freeze-dried plasma is a possible solution to the logistical challenges of providing plasma to forward deployed areas. The French army has been using freeze-dried and secured plasma (FDSP) since 1994. Plasma separated from fresh blood is lyophilized to produce FDSP. It is compatible with any blood type and easily rehydrated with 200 mL of water for injections in less than 3 minutes. After more than 2 years of storage at ambient temperature, the fibrinogen and clotting factor levels of FDSP are equivalent to those of fresh frozen plasma.<sup>36–38</sup> There is now increasing international interest in using freeze-dried plasma for remote DCR,<sup>39,40</sup> despite regulatory challenges.

Fibrinogen concentrate is another possible solution. Fibrinogen is the first coagulation factor to decrease during trauma-induced coagulopathy, suggesting that pharmacological replacement might reverse coagulopathy. Cryoprecipitate is currently used to provide fibrinogen replacement for trauma patients in European trauma centres. There is increasing interest in substituting fibrinogen concentrate for cryoprecipitate in bleeding trauma patients.<sup>41,42</sup> Fibrinogen concentrate is supplied in a powder that is stable and can be reconstituted easily and administered in the field. The CAF is conducting a pilot randomized controlled trial looking at fibrinogen concentrate in trauma patients.

One last solution to the logistical challenges of doing remote DCR is implementing a fresh whole blood transfusion program. There are many potential benefits to this strategy.<sup>43</sup> Fresh whole blood is warm, requires little logistical chain to administer in the field and contains all clotting factors. These advantages and challenges of implementing a fresh whole blood transfusion protocol are reviewed in the article by Beckett and colleagues.<sup>43</sup>

### Damage control surgery

NATO clearly defines DCS; it consists of emergency surgical procedures and treatment by a surgical team to stabilize casualties in order to save life, limb or function.<sup>6</sup> Damage control surgery techniques are applied when the magnitude of tissue and organ damage are such that definitive surgery is likely to exceed the casualty's physiologic limits. Examples of emergency DCS procedures include

cricothyrotomy for definitive airway control, laparotomy or thoracotomy for control of exsanguinating hemorrhage, laparotomy to control enteric spillage and temporary restoration of blood flow to a limb using vascular shunts. Definitive surgery is then delayed until various physiologic and other relevant parameters have been restored to as near normal as possible. In NATO doctrine, primary surgery describes the surgery directed at repair of the local damage caused by wounding, rather than correcting the generalized effects;<sup>6</sup> this can be equated with definitive surgery. The implication of distinguishing between DCS and primary surgery (definitive surgery) is that continuity and quality of care during MEDEVAC between Role 2 and 3 MTFs is required to optimize outcomes.

Originally, Rotondo and colleagues<sup>44</sup> described 3 separate and distinct aspects to DCS. The first phase of a DCS operation involves obtaining surgical control of both hemorrhage and contamination. During this initial operation, definitive repair of organs (e.g., bowel anastomosis) is deferred until the patient's physiologic status is more favorable. The laparotomy is abruptly terminated and temporary abdominal closure is commenced. The second phase is continued DCR: rewarming, correction of coagulopathy and maximization of hemodynamic parameters. The third phase can be instituted once normal physiology has been restored. Blackburne<sup>45</sup> defined "normal physiology" as temperature above 36°C, base deficit greater than -5 meq/L, lactate normalization, urine output greater than 50 mL/h, correction of coagulopathy, and FiO<sub>2</sub> less than 50%. Definitive surgical management of underlying injuries can then occur.<sup>45</sup>

Recently, minimally invasive techniques have been increasingly used to obtain definitive hemorrhage control in specific circumstances. Pelvic bleeding after blunt trauma has traditionally been difficult to control surgically. Although recent reports have documented success with preperitoneal packing of pelvic bleeding,<sup>46,47</sup> angiographic embolization of pelvic bleeding has become a mainstay for definitive control of massive pelvic bleeding<sup>48-50</sup> after blunt trauma. This technique of angiographic embolization of pelvic bleeding currently requires fluoroscopy. However, newer techniques are now being developed where intra-aortic balloon occlusion is being used to obtain temporary hemorrhage control of intra-abdominal and pelvic bleeding without the need of fluoroscopy.<sup>51-54</sup> A recent analysis has even suggested that this technique of resuscitative endovascular balloon occlusion of the aorta (REBOA) could have potentially prevented a substantial number of UK combat deaths if it had been available.<sup>55</sup> Because REBOA does not require fluoroscopy, it has the potential of being deployed far forward as part of a remote DCR capability.

Damage control surgical techniques are now also being applied to extremity injuries. Orthopedic DCS consists of early temporary stabilization of fractures (rapid splinting or external fixation) to minimize blood loss, protect soft tis-

sues, minimize fat embolism and assist in transportation. Vascular damage control involves a truncated approach of early and rapid revascularization, most often with an interposition shunt.<sup>56,57</sup> Early external fixation offers the added advantage of providing skeletal stability to protect temporary vascular shunts or definitive repairs.<sup>58,59</sup> Extremity damage control also involves débridement of grossly contaminated tissues and the liberal use of fasciotomies. In a retrospective study, Guerrero and colleagues<sup>60</sup> found that the incidence of limb loss was higher in patients with compartment syndrome, confirming that early and aggressive fasciotomies will significantly impact limb salvage rates. Another study of 336 combat casualties who underwent fasciotomy found that early compartment release (before air evacuation) was associated with better outcomes, notably less necrotic muscle and a lower rate of amputation.<sup>61</sup> Following the initial damage control procedures, definitive vascular and bony reconstruction and soft tissue coverage are performed sequentially at higher echelons of care.

#### *Implications on the capabilities of NATO medical modules*

As future field medical forces modularize their medical capabilities in accordance with new NATO doctrine, participating countries will need to consider what capabilities they might incorporate for each module. Particularly, recent developments in DCR and DCS may impact how the core modules of emergency department care and DCS (initial surgery) should be constituted.

For the emergency department care module (DCR), there is the option of incorporating a remote DCR capability. One challenge with this would be the logistical challenge associated with conducting hemostatic resuscitation in an austere environment where thawed blood products may not be available. Options available to NATO countries include freeze-dried plasma, fibrinogen concentrate, or a fresh whole blood transfusion capability. If a country does not have a dedicated search and rescue capability, it may also consider investing in a dedicated combat search and rescue capability. If this capability is desired, each country has to consider what level of provider will provide in-transit resuscitation for this combat search and rescue capability: medical technician, physician assistant or physician providers.

Hemorrhage control is the indispensable aspect of DCS. Considerations should include innovative methods for hemorrhage control within the DCS module. Angiographic embolization of pelvic bleeders is such a modality and requires fluoroscopy. A decision to include this capability within the DCS module would also need to take into consideration the considerable logistical challenges associated with transporting, maintaining and running a fluoroscopic capability. This decision may be helped by deciding whether or not damage control orthopedic surgery capabilities will

be included in the module. If damage control orthopedic surgery is included, it still is possible that fluoroscopy is not required; damage control orthopedics may just include plaster splinting of fractures or application of temporary external fixators without fluoroscopy. However, the deployment of fluoroscopic capability with the DCS module may be useful both for hemorrhage control and for damage control orthopedic surgery and so should remain a consideration.

In addition, REBOA is a new, innovative procedure that NATO countries may wish to deploy with their DCS modules. However, countries may also consider deploying a REBOA capability with its emergency department care module instead. If adopted, REBOA could be deployed as part of a remote DCR capability at a Role 1 facility or during tactical evacuation on a rotary wing platform.

## CONCLUSION

New developments in DCR and DCS may have an impact on how NATO countries develop their core and enhanced modules for medical treatment facilities. Canada will continue to collaborate with NATO and other allied nations to further develop the knowledge and concepts to enable and enhance the provision of high-quality combat casualty care.

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**Competing interests:** None declared.

**Contributors:** H. Tien, A. Beckett, M. Talbot, D. Pannell and T. Alabbasi designed the study. T. Alabbasi acquired and analyzed the data, which N. Garraway also analyzed. H. Tien, A. Beckett, D. Pannell and T. Alabbasi wrote the article, which all authors reviewed and approved for publication.

## References

- Government of Canada. National Defence and the Canadian Armed Forces. "About the Canadian Armed Forces." Available: [www.forces.gc.ca/en/about/canadian-armed-forces.page](http://www.forces.gc.ca/en/about/canadian-armed-forces.page) (accessed 2014 Oct. 28).
- Government of Canada. National Defence and the Canadian Armed Forces. "Caring for Our Own." Available: [www.forces.gc.ca/en/about-reports-pubs-health/caring-for-our-own.page](http://www.forces.gc.ca/en/about-reports-pubs-health/caring-for-our-own.page) (accessed 2014 Oct. 28).
- Robb DJ. NATO smart defence. 2013 Available: <http://amops.org/wp-content/uploads/2013/05/AMOPSRobbNATO.pdf> (accessed 2014 Oct. 28).
- Brisebois R, Hennecke P, Kao R, et al.; Canadian Forces Health Services Research Consortium. The Role 3 multinational medical unit at Kandahar Airfield 2005-2010. *Can J Surg* 2011;54:S124-9.
- Government of Canada. National Defence and the Canadian Armed Forces. "The Canada-U.S. Defence Relationship." Available: [www.forces.gc.ca/en/news/article.page?doc=the-canada-u-s-defence-relationship/hob7hd8s](http://www.forces.gc.ca/en/news/article.page?doc=the-canada-u-s-defence-relationship/hob7hd8s) (accessed 2015 May 1).
- North Atlantic Treaty Organization. Allied Joint Publication 4-10(A) Allied Joint Medical Doctrine; 2011.
- North Atlantic Treaty Organization. Allied Command Operations (ACO) Directive 83-1 on Medical Support to Operations; 2009.
- Allied Command Transformation. Conceptual basis for a modular approach to medical support capability. Enclosure to IMSM-0289-2012; 2012 Jul. 18.
- Savage E, Forestier C, Withers N, et al. Tactical combat casualty care in the Canadian Forces: lessons learned from the Afghan war. *Can J Surg* 2011;54:S118-23.
- Butler F. Tactical combat casualty care: combining good medicine with good tactics. *J Trauma* 2003;54(Suppl):S2-3.
- Galvagno SM, Jr1, Haut ER, Zafar SN, et al. Association between helicopter vs ground emergency medical services and survival for adults with major trauma. *JAMA* 2012;307:1602-10.
- Baxt WG, Moody P. The impact of a rotorcraft aeromedical emergency care service on trauma mortality. *JAMA* 1983;249:3047-51.
- Morrison JJ, DuBose JJ, O'Reilly DJ, et al. En-route care capability from point of injury impacts mortality after severe wartime injury. *Ann Surg* 2013;257:330-4.
- Apodaca A, Olson CM Jr, Bailey J, et al. Performance improvement evaluation of forward aeromedical evacuation platforms in Operation Enduring Freedom. *J Trauma Acute Care Surg* 2013;75(Suppl 2):S157-63.
- Mabry RL, Apodaca A, Penrod J, et al. Impact of critical care-trained flight paramedics on casualty survival during helicopter evacuation in the current war in Afghanistan. *J Trauma Acute Care Surg* 2012;73(Suppl 1):S32-7.
- Jansen JO, Thomas R, Loudon MA, et al. Damage control resuscitation for patients with major trauma. *BMJ* 2009;338:b1778
- Hess JR, Brohi K, Dutton RP, et al. The coagulopathy of trauma: a review of mechanisms. *J Trauma* 2008;65:748-54.
- Holcomb JB, Jenkins D, Rhee P, et al. Damage control resuscitation: directly addressing the early coagulopathy of trauma. *J Trauma* 2007; 62:307-10.
- Brohi K, Singh J, Heron M, et al. Acute traumatic coagulopathy. *J Trauma* 2003;54:1127-30.
- Niles SE, McLaughlin DF, Perkins JG, et al. Increased mortality associated with the early coagulopathy of trauma in combat casualties. *J Trauma* 2008;64:1459-63.
- Bickell WH, Wall M, Pepe P, et al. Immediate versus delayed fluid resuscitation for hypotensive patients with penetrating torso injury. *N Engl J Med* 1994;331:1105-9.
- Morrison CA, Carrick MM, Norman MA, et al. Hypotensive resuscitation strategy reduces transfusion requirements and severe postoperative coagulopathy in trauma patients with hemorrhagic shock: preliminary results of a randomized controlled trial. *J Trauma* 2011;70:652-63.
- Borgman MA, Spinella PC, Perkins JG, et al. The ratio of blood products transfused affects mortality in patients receiving massive transfusions at a combat support hospital. *J Trauma* 2007;63:805-13.
- Zink KA, Sambasivan CN, Holcomb JB, et al. A high ratio of plasma and platelets to packed red blood cells in the first 6 hours of massive transfusion improves outcomes in a large multicenter study. *Am J Surg* 2009;197:565-70.
- Cotton BA, Gunter OL, Isbell J, et al. Damage control hematology: the impact of a trauma exsanguination protocol on survival and blood product utilization. *J Trauma* 2008;64:1177-82.
- Hess JR, Holcomb JB, Hoyt DB. Damage control resuscitation: the need for specific blood products to treat the coagulopathy of trauma. *Transfusion* 2006;46:685-6.
- Holcomb JB, Jenkins D, Rhee P, et al. Damage control resuscitation: directly addressing the early coagulopathy of trauma. *J Trauma* 2007; 62:307-10.
- Cotton BA, Reddy N, Hatch QM, et al. Damage control resuscitation is associated with a reduction in resuscitation volumes and improvement in survival in 390 damage control laparotomy patients. *Ann Surg* 2011;254:598-605.
- Duchesne JC, Heaney J, Guidry C, et al. Diluting the benefits of hemostatic resuscitation: a multi-institutional analysis. *J Trauma Acute Care Surg* 2013;75:76-82.
- Nascimento B, Callum J, Tien H, et al. Effect of a fixed-ratio (1:1:1) transfusion protocol versus laboratory-results-guided transfusion in patients with severe trauma: a randomized feasibility trial. *CMAJ* 2013;185:E583-9.

31. Baraniuk S, Tilley BC, del Junco DJ, et al.; PROPPR Study Group. Pragmatic Randomized Optimal Platelet and Plasma Ratios (PROPPR) trial: design, rationale and implementation. *Injury* 2014; 45:1287-95.
32. CRASH-2 trial collaborators, Shakur H, Roberts I, et al. Effects of tranexamic acid on death, vascular occlusive events, and blood transfusion in trauma patients with significant haemorrhage (CRASH-2): a randomised, placebo-controlled trial. *Lancet* 2010;376:23-32.
33. Morrison JJ, Dubose JJ, Rasmussen TE, et al. Military application of tranexamic acid in trauma emergency resuscitation (MATTERS) study. *Arch Surg* 2012;147:113-9.
34. Gerhardt RT, Strandenes G, Cap AP, et al. PC; THOR Network and RemTORN Study Groups. Remote damage control resuscitation and the Solstrand Conference: defining the need, the language, and a way forward. *Transfusion* 2013;53(Suppl 1):9S-16S.
35. Kim BD, Zielinski MD, Jenkins DH, et al. The effects of prehospital plasma on patients with injury: a prehospital plasma resuscitation. *J Trauma Acute Care Surg* 2012;73(Suppl 1):S49-53.
36. Daban JL, Clapson P, Ausset S, et al. Freeze dried plasma: a French army specialty. *Crit Care* 2010;14:412.
37. Sailliol A, Martinaud C, Cap AP, et al. The evolving role of lyophilized plasma in remote damage control resuscitation in the French Armed Forces Health Service. *Transfusion* 2013;53(Suppl 1):65S-71S.
38. Martinaud C, Ausset S, Deshayes AV, et al. Use of freeze-dried plasma in French intensive care unit in Afghanistan. *J Trauma* 2011; 71:1761-4.
39. Glassberg E, Nadler R, Gendler S, et al. Freeze-dried plasma at the point of injury: from concept to doctrine. *Shock* 2013;40:444-50.
40. Glassberg E, Nadler R, Rasmussen TE, et al. Point-of-injury use of reconstituted freeze dried plasma as a resuscitative fluid: a special report for prehospital trauma care. *J Trauma Acute Care Surg* 2013; 75(Suppl 2):S111-4.
41. Meyer MA, Ostrowski SR, Windeløv NA, et al. Fibrinogen concentrates for bleeding trauma patients: What is the evidence? *IJ* 2011;101:185-90.
42. Aubron C, Reade MC, Fraser JF, et al. Efficacy and safety of fibrinogen concentrate in trauma patients — a systematic review. *J Crit Care* 2014;29:471.e11-7.
43. Beckett A, Callum J, da Luz LT, et al. Fresh whole blood transfusion capability for Special Operations Forces. *Can J Surg* 2015;58(3 Suppl 3):S153-6.
44. Rotondo MF, Schwab CW, McGonigal MD, et al. "Damage control": an approach for improved survival in exsanguinating penetrating abdominal injury. *J Trauma* 1993;35:375-82.
45. Blackburn LH. Combat damage control surgery. *Crit Care Med* 2008; 36(Suppl.): S304-S310.
46. Burlew CC, Moore EE, Smith WR, et al. Preperitoneal pelvic packing/ external fixation with secondary angioembolization: optimal care for life-threatening hemorrhage from unstable pelvic fractures. *J Am Coll Surg* 2011;212:628-35.
47. Beckett A, Tien H. What's new in operative trauma surgery in the last 10 years. *Curr Opin Crit Care* 2013;19:599-604.
48. Schwartz DA, Medina M, Cotton BA, et al. Are we delivering two standards of care for pelvic trauma? Availability of angioembolization after hours and on weekends increases time to therapeutic intervention. *J Trauma Acute Care Surg* 2014;76:134-9.
49. Metsemakers WJ, Vanderschot P, Jennes E, et al. Transcatheter embolotherapy after external surgical stabilization is a valuable treatment algorithm for patients with persistent haemorrhage from unstable pelvic fractures: outcomes of a single centre experience. *Injury* 2013;44:964-8.
50. Velmahos GC, Chahwan S, Hanks SE, et al. Angiographic embolization of bilateral internal iliac arteries to control life-threatening hemorrhage after blunt trauma to the pelvis. *Am Surg* 2000;66:858-62.
51. Scott DJ, Eliason JL, Villamaria C, et al. A novel fluoroscopy-free, resuscitative endovascular aortic balloon occlusion system in a model of hemorrhagic shock. *J Trauma Acute Care Surg* 2013; 75:122-8.
52. Morrison JJ, Lendrum RA, Jansen JO. Resuscitative endovascular balloon occlusion of the aorta (REBOA): A bridge to definitive haemorrhage control for trauma patients in Scotland? *Surgeon* 2014; 12:119-20.
53. Brenner ML, Moore LJ, DuBose JJ, et al. A clinical series of resuscitative endovascular balloon occlusion of the aorta for hemorrhage control and resuscitation. *J Trauma Acute Care Surg* 2013;75:506-11.
54. Morrison JJ, Percival TJ, Markov NP, et al. Aortic balloon occlusion is effective in controlling pelvic hemorrhage. *J Surg Res* 2012; 177:341-7.
55. Morrison JJ, Ross JD, Rasmussen TE, et al. Resuscitative endovascular balloon occlusion of the aorta: a gap analysis of severely injured UK combat casualties. *Shock* 2014;41:388-93.
56. Taller J, Kamdar JP, Greene JA, et al. Temporary vascular shunts as initial treatment of proximal extremity vascular injuries during combat operations: the new standard of care at Echelon II facilities? *J Trauma* 2008;65:595-603.
57. Fox CJ, Gillespie DL, Cox ED, et al. Damage control resuscitation for vascular surgery in a combat support hospital. *J Trauma* 2008; 65:1-9.
58. Mathieu L, Bazile F, Barthélémy R, et al. Damage control orthopaedics in the context of battlefield injuries: the use of temporary external fixation on combat trauma soldiers. *Orthop Traumatol Surg Res* 2011;97:852-9.
59. Andersen RC, Ursua VA, Valosen JM, et al. Damage control orthopaedics: an in-theater perspective. *J Surg Orthop Adv* 2010;19:13-7.
60. Guerrero A, Gibson K, Kralovich KA, et al. Limb loss following lower extremity arterial trauma: What can be done proactively? *Injury* 2002;33:765-9.
61. Ritenour AE, Dorlac WC, Fang R, et al. Complications after fasciotomy revision and delayed compartment release in combat patients. *J Trauma* 2008;64:S153-61.