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

Fluid Resuscitation in Tactical Combat Casualty Care: Yesterday and Today

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The prevailing wisdom for the prehospital fluid resuscitation of trauma victims in hemorrhagic shock in 1992 was to administer 2 L of crystalloid solution as rapidly as possible. A review of the fluid resuscitation literature found that this recommendation was not well supported by the evidence at the time. Prehospital fluid resuscitation strategies were reevaluated in the 1993–1996 Tactical Combat Casualty Care (TCCC) research program. This article reviews the advances in prehospital fluid resuscitation as recommended by the original TCCC Guidelines and modified over the following 2 decades. These advances include hypotensive resuscitation, use of prehospital whole blood or blood components when feasible, and use of Hextend or selected crystalloids when logistical considerations make blood or blood component use not feasible.

Keywords: fluid resuscitation, Hextend, whole blood, dried plasma, hypotensive resuscitation

Prehospital fluid resuscitation strategy prior to Tactical Combat Casualty Care

The original Tactical Combat Casualty Care (TCCC) article in 1996 noted that, despite its widespread use, the benefit of fluid resuscitation using crystalloid solutions for trauma victims in hemorrhagic shock had not been well established.[1–13] The recommended regimen for fluid resuscitation in civilian trauma courses at the time was to administer 2 L of either lactated Ringer's (LR) or normal saline as rapidly as possible.

TCCC fluid resuscitation for hemorrhagic shock: 1996

Much of the presumed benefit of fluid resuscitation for hemorrhagic shock as practiced prior to 1996 was based on animal models of hemorrhage in which the animals were bled a specified fraction of their blood volume. The blood loss was then stopped and fluid resuscitation was accomplished—a so-called "controlled hemorrhage" model.[14,15] In other models, in which an injury was created and experimental animals were allowed to bleed freely from the injury site, aggressive fluid resuscitation was found to be of no benefit or to actually increase mortality.[16–22] Proposed reasons for the lack of benefit of fluid resuscitation in these uncontrolled hemorrhage models include vasodilation with increased blood flow to the site of bleeding, dilution of clotting factors, and increased intravascular pressure—all of which could interfere with attempted clot formation.

A large prospective, randomized, controlled trial performed by Bickell et al found that aggressive early resuscitation with crystalloid for hypotensive patients with penetrating wounds of the chest and/or abdomen resulted in increased mortality compared with patients in whom fluid resuscitation was delayed until after surgical control of bleeding had been accomplished.[7]

The original TCCC article also re-evaluated the recommendation of crystalloid for fluid resuscitation in hemorrhagic shock. Both LR and normal saline are crystalloids, which means that their primary osmotically active particle is sodium. Because the sodium ion distributes quickly throughout the entire extracellular fluid compartment and the water component of the solution follows, crystalloids redistribute rapidly from the intravascular space to the extravascular space. This means that a casualty in hemorrhagic shock who is

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administered 1000 mL of LR will have only 200 mL of that volume in his or her intravascular space 1 hour later.[23–25] This shift can both allow for a recurrence of hypotension and contribute to adverse secondary effects of fluid administration, such as pulmonary edema, cerebral edema, and abdominal compartment syndrome.[1,26]

Colloids, in contrast, contain larger molecules in solution that are retained within the intravascular space. Hespan, for example, contains the large hetastarch molecule, and the entire infused volume is retained in the intravascular space for 8 hours or longer.[27] In 1996, hetastarch was found to be a safe and effective alternative to LR in resuscitation of casualties with controlled hemorrhagic shock.[28,29]

Based on these considerations, the recommendations for fluid resuscitation in the original TCCC article were to

- delay starting intravenous (IV) lines and performing fluid resuscitation until the Tactical Field Care phase
- withhold IV fluids in casualties who are not in shock
- withhold IV fluids in casualties who are in shock as a result of uncontrolled hemorrhage
- resuscitate casualties in shock as a result of hemorrhage that has been effectively controlled with an initial volume of 1000 mL of Hespan
- limit Hespan to 1500 mL or less[1]

The 1999 TCCC Mogadishu Workshop

After the events of the Battle of Mogadishu were published in the book *Blackhawk Down*, the details of the casualties sustained in that combat action became known. In December 1999, at the annual meeting of the Special Operations Medical Association, the United States Special Operations Command funded a 1-day workshop to review the injuries sustained by the US casualties in Mogadishu, the treatment provided to them, and the casualty outcomes in order to determine whether there were lessons learned from that battle that should be incorporated into TCCC.

One of the topics discussed at the Mogadishu workshop was the fluid resuscitation recommendations in TCCC. There was a clear consensus among trauma experts in the panel that casualties with mental status changes due to shock should be given enough fluid to resuscitate them to the point that mentation improves, even in cases in which the casualty's shock was the result of noncompressible (internal) hemorrhage. Panel members noted that the goal of resuscitation should not be to restore a "normal" blood pressure, but to produce improved mentation. Although little evidence was cited to support this recommendation, the opinions of the expert panelists were unanimous on this point.[30]

The US Army Medical Research and Materiel Command (MRMC) and Office of Naval Research Fluid Resuscitation Conferences 2001–2002

The interest generated in fluid resuscitation as a result of the 1996 TCCC paper and the 1999 Mogadishu Workshop spurred the United States Army Medical Research and Material Command (MRMC) and the Office of Naval Research (ONR) to sponsor a series of fluid resuscitation conferences in 2001 and 2002. These conferences were chaired by Dr John Holcomb and Dr Howard Champion and produced a hypotensive fluid resuscitation strategy to be used for casualties with either controlled or uncontrolled hemorrhage. This strategy also recommended the use of the synthetic hetastarch solution Hextend instead of the previously used Hespan because of the former's lesser adverse impact on coagulation status.[31,32]

Additional research by Sondeen et al[33] at the United States Army Institute of Surgical Research (USAISR) produced further insights into resuscitation and rebleeding in uncontrolled hemorrhage. Sondeen's team found that in 70 swine with aortotomies, 5 animals died before fluid resuscitation and 3 more died at onset of fluid resuscitation. For the remaining 62 animals, rebleeding occurred at a mean systolic blood pressure 94 mm Hg. This study documented that, in this animal model of severe bleeding, there was a blood pressure of threshold above which further resuscitation caused disruption of the body's attempt to establish hemostasis, effectively establishing an upper limit for resuscitation of casualties with noncompressible hemorrhage that has not yet been surgically controlled.[33]

TCCC fluid resuscitation for hemorrhagic shock: 2003

After the MRMC and ONR fluid resuscitation conferences and the work done by Sondeen et al, the newly formed Committee on Tactical Combat Casualty Care (CoTCCC) voted to modify the recommendations for fluid resuscitation in TCCC. The new guideline also incorporated a recommendation made at a CoTCCC meeting by Dr Peter Rhee that conscious casualties should be permitted to take water by mouth to prevent going to surgery dehydrated.[34] The updated fluid resuscitation guideline was as follows:

- Assess for hemorrhagic shock—altered mental status (in the absence of head injury) and weak or absent peripheral pulses are the best field indicators of shock