The marriage of surgical simulation and telementoring for damage-control surgical training of operational first responders: a pilot study
Kirkpatrick, Andrew W.; Tien, Homer; LaPorta, Anthony T.; Lavell, Kit; Keillor, Jocelyn; Wright Beatty, Heather E.; McKee, Jessica Lynn; Brien, Susan; Roberts, Derek J.; Wong, Jonathan; Ball, Chad G.; Beckett, Andrew

This publication could be one of several versions: author's original, accepted manuscript or the publisher's version. / La version de cette publication peut être l'une des suivantes : la version prépublication de l'auteur, la version acceptée du manuscrit ou la version de l'éditeur.
For the publisher's version, please access the DOI link below./ Pour consulter la version de l'éditeur, utilisez le lien DOI ci-dessous.

Publisher's version / Version de l'éditeur:
https://doi.org/10.1097/TA.0000000000000829
Journal of Trauma and Acute Care Surgery, 79, 5, pp. 741-747, 2015-09-29

L’accès à ce site Web et l’utilisation de son contenu sont assujettis aux conditions présentées dans le site https://publications-cnrc.canada.ca/fra/droits
LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D’UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n’arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.
The marriage of surgical simulation and telementoring for damage-control surgical training of operational first responders: A pilot study

Andrew W. Kirkpatrick, MD, Homer Tien, MD, Anthony T. LaPorta, MD, Kit Lavell, Jocelyn Keillor, PhD, Heather E. Wright Beatty, PhD, Jessica Lynn McKee, MSc, Susan Brien, MD, Derek J. Roberts, MD, PhD, Jonathan Wong, Chad G. Ball, MD, and Andrew Beckett, MD, Calgary, Alberta, Canada

BACKGROUND: Hemorrhage is the leading cause of preventable posttraumatic death. Many such deaths may be potentially salvageable with remote damage-control surgical interventions. As recent innovations in information technology enable remote specialist support to point-of-care providers, advanced interventions, such as remote damage-control surgery, may be possible in remote settings.

METHODS: An anatomically realistic perfused surgical training mannequin with intrinsic fluid loss measurements (the “Cut Suit”) was used to study perihepatic packing with massive liver hemorrhage. The primary outcome was loss of simulated blood (water) during six stages, namely, incision, retraction, direction, identification, packing, and post-packing. Six fully credentialed surgeons performed the same task as 12 military medical technicians who were randomized to remotely telementored (RTM) (n = 7) or unmentored (UTM) (n=5) real-time guidance by a trauma surgeon.

RESULTS: There were no significant differences in fluid loss between the surgeons and the UTM group or between the UTM and RTM groups. However, when comparing the RTM group with the surgeons, there was significantly more total fluid loss (p = 0.001) and greater loss during the identification (p = 0.002), retraction (p = 0.035), direction (p = 0.014), and packing (p = 0.022) stages. There were no significant differences in fluid loss after packing between the groups despite differences in the number of sponges used; RTM group used more sponges than the surgeons and significantly more than the UTM group (p = 0.048). However, mentoring significantly increased self-assessed nonsurgeon procedural confidence (p = 0.004).

CONCLUSION: Perihepatic packing of an exsanguinating liver hemorrhage model was readily performed by military medical technicians after a focused briefing. While real-time telementoring did not improve fluid loss, it significantly increased nonsurgeon procedural confidence, which may augment the feasibility of the concept by allowing them to undertake psychologically daunting procedures. (J Trauma Acute Care Surg. 2015;79: 741–747. Copyright © 2015 Wolters Kluwer Health, Inc. All rights reserved.)

KEY WORDS: Operational medicine; tactical medicine; telemedicine; damage-control surgery; surgical simulation.

Submitted: April 22, 2015, Revised: May 22, 2015, Accepted: May 22, 2015, Published online: September 29, 2015.
From the Canadian Forces Health Services (A.W.K., H.T., J.W., A.B.); Departments of Surgery (A.W.K., D.J.R., C.G.B.), Critical Care Medicine (A.W.K.), and Community Health Sciences (D.J.R.), and Regional Trauma Services (A.W.K., C.G.B.), Foothills Medical Centre; and Innovative Trauma Care (J.L.M.), Edmonton, Calgary, Alberta; Sunnybrook Health Sciences Centre (H.T.), Toronto; and Royal College of Physicians and Surgeons (S.B.), and Flight Research Laboratory (J.K., H.E.W.B.), National Research Council of Canada, Ottawa, Ontario, Canada; Rocky Vista University, Parker, Colorado (A.T.L.); and Strategic Operations (K.L.), San Diego, California.

Trial Registration: ID ISRCTN/77929274.
This is an open-access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives 3.0 License, where it is permissible to download and share the work provided it is properly cited. The work cannot be changed in any way or used commercially.

This study was presented at the annual meeting of the Trauma Association of Canada, April 9–10, 2015, in Calgary, Alberta, Canada.

The opinions expressed herein represent those of the authors alone and do not reflect any official policies or opinions representative of the Canadian Forces or any other official departments of the Governments of Canada or the United States. Supplemental digital content is available for this article. Direct URL citations appear in the printed text, and links to the digital files are provided in the HTML text of this article on the journal’s Web site (www.jtrauma.com).

Address for reprints: Andrew W. Kirkpatrick, CD, MD, MHSC, Regional Trauma Services, EG23 Foothills Medical Centre, Calgary, Alberta, T2N 2T9; email: Andrew.kirkpatrick@albertahealthservices.ca.

DOI: 10.1097/TA.0000000000000829

J Trauma Acute Care Surg
Volume 79, Number 5
741

Most battlefield casualties die of their injuries before ever reaching a surgeon.1–3 Before recent conflicts in Iraq and Afghanistan, studies found that traumatic hemorrhage resulted in more than 50% of all battlefield deaths.2 However, these recent conflicts have been characterized by a different type of warfare, asymmetric warfare against nontraditional combatants and small unit engagements instead of the set piece battles of the last century.1 As a result, hemorrhagic deaths have become even more prominent. Eastridge et al.1 reported that during Operation Iraqi Freedom and Operation Enduring Freedom, 87% of all battlefield injury fatalities occurred in the pre–medical treatment facility environment. Most (67%) of these were truncal injuries, with extremity (14%) and junctional (19%) injuries being less common sites.1 Much progress has been made in addressing both extremity and junctional hemorrhage, including improvements in techniques, system design, and pharmacology.4,6 With the aggressive training and dissemination of tourniquet use, an 85% decrease in peripheral extremity hemorrhage mortality has been documented.1 While junctional hemorrhage has been long considered a treatment gap in hemorrhage control, much attention and energy has been directed to addressing this challenge with a number of novel devices being introduced and trialed such as the Combat Ready Clamp (CRoC)7 and the iTClamp.8 However, there
has been limited progress in developing techniques to control exsanguinating truncal hemorrhage in the pre–medical treatment facility environment, other than admonitions to decrease the time from point of injury to surgical intervention.\(^1\) Damage-control surgery refers to abbreviated techniques used when either the patient’s physiologic reserve or the “local capabilities” of a care setting are inadequate.\(^9,10\) Placing packs around bleeding solid organs and leaving the abdomen open are basic elements of damage-control surgery. Recently, remote damage-control resuscitation (RDCR) has been conceived as a method of extending damage-control principles to point of injury.\(^11\) Of all the important concepts embraced by RDCR, control of compressible hemorrhage and rapid surgical control of bleeding are the most difficult to achieve in the prehospital setting. However, we believe that these concepts require urgent study. In terms of mechanics, performing a laparotomy by incising the anterior abdominal wall to access the peritoneal cavity is technically practical especially in healthy young subjects with normal to lean body mass and no previous surgery.\(^12\) Nonphysicians have been previously reported to perform this successfully,\(^13\) although this would be predicted to be very intimidating and stressful to a nonsurgeon. It is possible, however, that recent information technology advances may facilitate this.

Telemedicine is defined as providing medicine at a distance.\(^14\) Remote telementoring is a specific telemedical technique wherein a remote expert is able to guide a novice in performing medical procedures outside his or her normal scope of practice in an urgent medical situation, using information technology.\(^15\) Remote telementoring has global applications, essentially enabling providers to deliver advanced medical care via remote guidance anywhere on (or above the) earth, which has internet connectivity or satellite coverage.\(^16–19\) Much work in this area has already been done by NASA investigators, who have successfully demonstrated the ability to remotely telementor emergency ultrasound examinations.\(^20,21\) Furthermore, reports of the telementoring of surgical procedures have described there being no obvious differences in skill acquisition among telementored versus locally mentored surgeons.\(^22,23\) Thus, we sought to explore the practicalities of mentoring surgically naive but motivated first responders to perform damage-control laparotomies and packing of exsanguinating liver injuries as a means of obtaining surgical control of truncal injuries in austere circumstances.

**PATIENTS AND METHODS**

Ethical approval for this study was obtained from the University of Calgary (REB14-0634) and the National Research Council of Canada. This was a randomized nonblinded trial where medical technicians (MedTechs) in the Canadian Armed Forces were telementored to perform a trauma laparotomy with or without telementoring on a human patient simulator.

**Study Participants**

All participants were volunteers who were free to withdraw from the study at any time without consequence. Military MedTechs were recruited from the 1 Canadian Field Hospital, a national-level element that reports directly to the Canadian Forces Health Services and provides deployable tertiary-level medical and surgical assets in support of the Canadian Armed Forces. A separate control group of fully credentialed surgeons performed the same task as military MedTechs to establish a benchmark for the primary outcomes of the study. None of these surgeons were telementored.

**Independent Variable**

MedTechs were randomized to an unmentored (\(n = 5\)) (UTM) or remotely telementored (\(n = 7\)) (RTM) group, which included real-time guidance by a trauma surgeon. Those allocated to the RTM group received continuous instructions and feedback from an experienced trauma surgeon with previous telementoring experience.

**Equipment and Methods**

Mentored MedTechs wore a USB audio headset with built-in microphone (Logitech, Romanel-sur-Morges, Switzerland) and a head-mounted 1.3-Megapixel video camera (Logitech Webcam 2 Megapixel Autofocus, Karl-Zeiss lens 2.0/3.7, Lausanne, Switzerland), which captured their point of view of the operative procedures required. This video capture was thereafter displayed on the mentor’s laptop computer (HP Probook 4520s, Hewlett Packard, Palo Alto, CA) through the use of Skype (Luxembourg City, Luxembourg), which provided for one-way visual and two-way audio communication over an encrypted Internet connection (Fig. 1). All study procedures were conducted in a ground floor room of a research building for all mentored procedures, with the remote mentor residing within a separate room on a separate floor of the same building using the internal wireless network.

**Outcome**

The primary outcome was “simulated blood loss” during a staged laparotomy on a surgical simulator with fluid loss measurement capabilities.

---

*Figure 1. Remote mentor’s screen illustrating the surgical simulator as viewed through the MedTechs head-mounted camera.*
Surgical Task

All participants were asked to perform a laparotomy with midline incision into the peritoneal cavity followed by sponge packing of an exsanguinating liver hemorrhage (see Video, Supplemental Digital Content 1, http://links.lww.com/TA/A630). These surgical tasks were performed on the torso and viscera of a customized “Cut Suit” Human Worn Partial Task Surgical Simulator (Strategic Operations, San Diego, CA), without a human actor. The standardized laparotomy was compartmentalized into six different phases, each with a 60-second time limit, with specific objective goals to be accomplished within each task (Table 1). This compartmentalization was intended to allow study of the various subtasks required within the overall laparotomy and to facilitate comparisons with future studies in the weightless windows of parabolic flight. The primary outcome was the amount of fluid loss for 60 seconds after the hemostasis phase.

The specially modified Cut Suit torso was equipped with a sensitive fluid flow meter that recorded both total fluid loss and fluid loss velocities and was equipped with a remote control fob for accurate measurement of simulated hemorrhage (Fig. 2). The pressure setting of the Cut Suit pump was consistently set to the maximum flow rate of 12 psi (82.74 kPa). A senior surgeon (university professor and former command military surgeon) acted as a dual surgical assistant and safety surgeon for all participants. He was instructed to assist only as requested by the UTM MedTechs and surgeons and responded only to remote direction from the mentor for the RTM cohort of MedTechs. He did not handle any instruments or packs and only retracted as directed. He had, however, the authority to terminate all procedures by any participant he felt potentially unsafe.

Randomization

After enrollment but before group allocation, all participants (including surgeons) were given a standardized introduction to the study, which included an introduction to damage-control surgery, the Cut Suit surgical trainer, and a tutorial on the basics of visceral packing for hemorrhage control (see Supplemental Digital Content 2, http://links.lww.com/TA/A631). After responding to questions and reinforcing the teaching, MedTechs were then randomized through random number generation to either laparotomy without telementoring (UTM) or laparotomy with remote telementoring (RTM).

The detailed study protocol is available online (see Supplemental Digital Content 3, http://links.lww.com/TA/A632). Prestudy questionnaires concerning demographics and previous surgical experience was administered to all participants (see

---

**TABLE 1.** Compartmentalized Stages of the Standardized Laparotomy and Hepatic Packing

| Surgical Task | Goal | Objective Evaluation |
|---------------|------|----------------------|
| Incision | Open the abdominal cavity without inadvertent visceral injury | Completely open (y/n) If incomplete, (%) open |
| Retraction | Insertion of a self-retaining surgical retractor | Placed correctly (y/n) |
| Direction | Direction of a surgical assist to place and manipulate a handheld abdominal retractor to augment visualization. | Visualization augmented (y/n) |
| Identification | Correctly identify the site of surgical bleeding | Site of bleeding correctly identified (y/n) |
| Hemostasis | Control of the visceral bleeding through the manual application of gauze sponges | The volume of shed fluid for 60 s after completion of the packing phase |
| Closure | Performance of a skin-only suture closure | Completely closed (y/n) If incomplete, (%) closed |

---

**Figure 2.** Simulated surgical suite for damage-control laparotomy and perihepatic packing. The torso and viscera of a customized Cut Suit (A) is being operated on by a nonsurgeon (B). Assistance is being provided only after a direct request from the experienced “safety surgeon” (C). Fluid loss representing the degree of massive hemorrhage is being measured by the calibrated fluid pump (D).
Study Group Performance During Simulated Laparotomy and Hepatic Packing

| Task                      | Surgeons | RMT       | UTM       |
|---------------------------|----------|-----------|-----------|
|                           | Median (IQR) | Median (IQR) | Median (IQR) |
| Incision fluid loss, mL   | 303 (397) | 669 (400) | 444 (463) |
| Incision time, s          | 23.97 (27.87) | 57.53 (28.44) | 34.38 (34.10) |
| Incision visceral Injury   | 0        | 0         | 0         |
| Retraction time, s        | 7.72 (22.43) | 20.50 (10.11) | 11.08 (22.68) |
| Retraction fluid loss, mL | 88 (291) | 255 (141) | 151 (291) |
| Direction time, s         | 6.27 (6.55) | 11.25 (10.82) | 8.03 (12.15) |
| Direction fluid loss, mL  | 73 (50) | 150 (126) | 108 (165) |
| Identification time, s    | 3.33 (5.26) | 6.21 (26.18) | 4.63 (4.71) |
| Identification fluid loss, mL | 51 (87) | 58 (50) | 81 (354) |
| Packing time, s           | 34.19 (40.20) | 60 (6.14) | 49.93 (28.84) |
| No. sponges               | 7 (10) | 9 (7) | 5 (8) |
| Packing fluid loss, mL    | 454 (552) | 785 (128) | 666 (350) |
| After packing fluid loss, mL | 801 (48) | 770 (210) | 790 (70) |
| Percentage skin incision closed | 0.19 (0.22) | 0 (0.09) | 0 (0.03) |
| Total fluid loss, mL      | 1,819 (675) | 2,721 (922) | 2,144 (874) |

This was significantly different between surgeons and RTM MedTechs ($p = 0.005$), but not between surgeons and UTM MedTechs ($p = 1.000$) or between the two groups of MedTechs ($p = 0.432$). When comparing surgeons with the RTM group, there was significantly greater loss during the identification ($p = 0.002$), retraction ($p = 0.035$), direction ($p = 0.014$), and packing ($p = 0.022$) stages. There were no significant differences in fluid loss after packing between the groups despite differences in the number of sponges used. The RTM MedTechs used more sponges under direction than surgeons and significantly more than UTM MedTechs ($p = 0.048$).

Mentoring significantly increased nonsurgeon procedural confidence when asked if damage-control laparotomy was a realistic task for them to perform ($p = 0.030$), if they felt confident in their current abilities to perform a damage-control laparotomy ($p = 0.004$), and if damage-control laparotomy would be less dangerous for the patient than beneficial in their hands ($p = 0.004$) for the RTM MedTechs compared with the UTM MedTechs. Surgeons were significantly more confident in their current ability to perform a damage-control laparotomy when compared with either RMT ($p = 0.002$) or UTM ($p = 0.004$) groups. The telementored group also felt strongly that telementoring was beneficial. When asked if they would want to be telementored again if they were asked to perform another laparotomy or if telementoring would increase their confidence when performing another laparotomy, subjects strongly agreed, answering a median of 5 of 5 on a Likert scale. When asked if telementoring would decrease their stress when performing another laparotomy, mentored subjects felt it would help, answering a median of 4 of 5 on the same scale (Table 2).

### Discussion

The Cut Suit is an anatomically accurate simulator that can be safely worn by humans and allows for the performance of a variety of complex, realistic surgeries and procedures as encountered in real casualties. After a relatively brief period of instruction, all nonsurgically trained military MedTechs...
were able to understand the basic principles and steps of a damage-control laparotomy and were able to perform one using a Cut Suit with simulated massive hemorrhage. Furthermore, after the completion of a surgical packing task, there was no significant difference in postpackaging fluid loss between any group, implying that if a novice responder can access the site of hemorrhage, then an effective but radical prehospital intervention might be provided.

Thus, theoretically otherwise unsurvivable casualties with no other treatment options might be offered such as a lifesaving intervention (LSI), considering that the most recent review of Canadian Forces deaths in Afghanistan automatically deemed all cases of torso exsanguination "nonpreventable."25 The Trauma Hemostasis and Oxygenation Research (THOR) Network has defined an LSI as a medical procedure that if not performed conveys a high probability of morbidity or death,11,26 with the terms far-forward and austere denoting environments in which professional health care providers do not normally operate.11 Delayed evacuations refer to situations in which evacuation times exceed 60 minutes and prolonged for more than 6 hours from point of wounding until arrival at a medical treatment facility capable of providing damage-control surgery.11 The current reality is that the wounded warriors of the future will increasingly be seriously injured in far-forward locations, facing prolonged or nonevacuations, being cared for by motivated but nonsurgically trained providers, yet requiring LSIs (most commonly for hemorrhage control) if they have a hope of survival.

Gerhardt et al.26 recently reviewed data from a forward operating base supporting urban combat. They found that while LSIs were required in most casualties requiring evacuation, the scope of practice required for performing these LSIs before medical treatment facility arrival were beyond that of conventional forces combat medics, and thus, few LSIs were performed by them near the point of injury. They thus speculated that emergency telemedical direction might enable the potential deployment of advanced LSIs, thus providing a more efficient RDCR to those most in need.26 Telemedicine is simply the provision of medical care at a distance using communication technologies. Remote telementoring is a form of telemedicine that involves a more experienced mentor providing guidance at a distance to a less experienced mentee who may be performing any number of required tasks.15,23,27,28 Mentoring may be best achieved in a "just in time" fashion where an appropriate mentor is available to facilitate problem solving in response to immediate needs.27 With ongoing improvements in technology and especially connectivity, it is likely that austere medical situations in the future will have access to remote medical direction. We used a conceptually (but not necessarily technically) simple model of hepatic packing. It is likely that other remote damage-control surgical techniques may also be telementorable, and further efforts will continue to evaluate these requirements. Any amount of prepreparation briefing would be highly desirable and augmentative to the flexibility in the scope telementoring provides.

Great strides have been made through the introduction of RDCR techniques and philosophies in recent years,11 with major advances in resuscitative techniques that a far-forward damage-control laparotomy might not be unthinkable. Chaudery et al.29 recently reviewed the current technologies potentially available in the prehospital setting to enable abdominal hemorrhage control in catastrophic hemorrhage, noting that most studies were preclinical in vivo trials. Of the potential techniques, specifically intra-abdominal foam injection30–32 and resuscitative endovascular aortic balloon occlusion,33,34 were considered as attractive candidates.29 Chaudery et al. notably did not consider prehospital open surgical interventions as a potential option despite noting that "manual force is one of the most effective means of controlling bleeding." However, as early as 1983, NASA think-tanks identified the ability to perform laparotomy as the minimum desirable surgical capability to save lives before transfer to earth, arguably one of the most dramatic prehospital settings.

In the present study, there was no difference in fluid loss between nonmentored MedTechs and surgeons; however, there was greater fluid loss in those being mentored. This was likely related to the technical settings of the Cut Suit, which has a versatile fluid loss capability. Thus, the selection of a 12 psi (82.74 kPa) hemorrhage rate, while accurately replicating conditions of exsanguination, was conducted at supraphysiologic pressures, greatly exaggerating any effect of delay, even appropriate delay, on fluid loss parameters in any group. We thus speculate that the mentored group had greater fluid loss because of the brief but inherent nature of a two-way communication between the mentor and the mentee. So while this delay likely explains increased fluid loss, the increased confidence that the mentored MedTechs reported was notable. Preliminary data still being fully analyzed noted that the while the RTM MedTechs demonstrated stress levels similar to those of the surgeons, the UTM MedTechs had significantly higher stress levels as indexed by the low frequency–to–high frequency ratio of heart rate variability (Jocelyn Keillor, personal communication, February 1, 2014). Therefore, one of the greatest benefits of the telepresence of an experienced and presumably emotionally distanced expert may be to bring reassurance and confidence to a far-forward responder, who will often unfortunately be extremely emotionally close to the victim.

The information technologies used were simple "off-the-shelf" software with two-way audio and one-way video display as this was a proof-of-concept study. The Skype proprietary "closed source" software is protected by multiple systems to address security and privacy.37 All information is sent over secured socket layer that uses 256-bit Advanced Encryption Standard (AES) for all the information, leaving a transmitting computer that can only be decrypted by the Skype server. Nonetheless, greater encryption will typically be required for special operations. It is only logical that ever greater information and encryption capabilities will continue to expand in the future. The same can be expected of the degree of communication richness between the mentor and the mentee. The mentored MedTechs could only hear the remote mentor. There are rapidly evolving technologies in which the mentor may in the future by able to telestrate38 on displayed images such as anatomy demonstration on a heads-up video display39 worn by the MedTech for instance.

**Limitations of the Study**

There are limitations to this study. We were not able to measure iatrogenic injuries as a result of improper laparotomy techniques. Therefore, this may have biased the study against...
telementored medics. More “simulated blood loss” was observed in the telementored group, as these medics took longer to open the abdomen and pack the solid organs. While the Cut Suit currently will demonstrate gross inadvertent bowel injuries and advances in the materials and construction of the model is constantly progressing, mammalian tissues are still perceived to be more susceptible to inadvertent injury. Thus, future complementary studies may be considered in animal models, where the outcome of interest is not only time to task completion and successful solid organ packing but also iatrogenic injuries to the bowel or other visceral structures.

In conclusion, perihepatic packing of an exsanguinating liver hemorrhage simulation was readily performed by military MedTechs after a focused briefing without obvious performance differences compared with trained surgeons. While real-time RTM did not improve study outcomes, it significantly increased nonsurgeon procedural confidence, which may increase the feasibility of the concept in actual operational application.

ACKNOWLEDGMENT

We thank Major Barbaramne Besenyodi, Major Douglas Kromrey, Master Warrant Officer Danyal Beale, Warrant Officer Paul Trudel, Warrant Officer (Retired) Patrick Papineau, Dr. Brett Mador, Dr. Michael Kim, Dr. Jacinthe Lampron, and Dr. Paul Cantle for supporting the study.

DISCLOSURE

This research was primarily funded by the Canadian Forces Health Services with support from the Royal College of Physicians and Surgeons on Canada. A.W.K. was the principal investigator of a randomized trial on open abdomen management funded by the Kinetic Concepts Corporation. A.W.K. has received travel reimbursement to attend laboratories from the Innovative Trauma Care, Synthes, and Life Cell Corporations and the donation of a NannoMax portable ultrasound machine for unrestricted research purposes from the Sonosite Corporation. J.L.M. is the research director of Innovative Trauma Care, Edmonton, Alberta, Canada. K.L. is the executive vice-president of Strategic Operations, San Diego, California.

REFERENCES

1. Eastridge BJ, Mabry RL, Seguin P, Cantrell J, Tops T, Uribe P, Mallett O, Zubko T, Oetjen-Gerdes L, Rasmussen TE, et al. Death on the battlefield (2001–2011): implications for the future of combat casualty care. J Trauma Acute Care Surg. 2012;73:S431–S437.
2. Bellamy RF. The causes of death in conventional land warfare: implications for combat casualty care. Mil Med. 1984;149:55–62.
3. Bellamy RF, Maningas PA, Vayer JS. Epidemiology of trauma: military experience. Ann Emerg Med. 1986;15:1384–1388.
4. CRASH-2 Collaborators IBS. Effect of tranexamic acid in traumatic brain injury: a nested randomized, placebo, controlled trial (CRASH-2 Intracranial Bleeding Study). Br Med J. 2011;343:d3795.
5. Beeckley AC, Sebesta JA, Blackbourne LH, Herbert GS, Kauvar DS, Baer DG, Walters TJ, Mullenis PS, Holcomb JB. Prehospital tourniquet use in Operation Iraqi Freedom: effect on hemorrhage control and outcomes. The Journal of trauma. 2008;64:S28–S37; discussion S.
6. Kotwal RS, Montgomery HR, Kotwal BM, Champion HR, Butler FK Jr, Mabry RL, Cain JS, Blackbourne LH, Mechtler KK, Holcomb JB. Eliminating preventable death on the battlefield. Arch Surg. 2011;146:1350–1358.
7. Khierabadi BS, Terrazas JB, Hanson MA, Kragh JF Jr, Dubick MA, Blackbourne LH. In vivo assessment of the Combat Ready Clamp to control junctional hemorrhage in swine. J Trauma Acute Care Surg. 2013;74:1260–1265.
8. Filips D, Loggsety S, Tan J, Atkinson I, Mottet K. The iTClamp controls junctional bleeding in a lethal swine exsanguination model. Prehosp Emerg Care. 2013;17:526–532.
9. Burch JM, Ortiz VB, Richardson RJ, Martin RR, Mattos KL, Jordan GL Jr. Abbreviated laparotomy and planned reoperation for critically injured patients. Ann Surg. 1992;215:476–483.
10. Mattos KL. Introduction, background, and future projections of damage control surgery. Surg Clin North Am. 1997;77:753–759.
11. Jenkins DH, Rappold JF, Baldone JF, Bersuës O, Blackbourne L, Brohi KH, Butler FK, Cap AP, Cohen MJ, Davenport R, et al. Trauma hemostasis and oxygenation research position paper on remote damage control resuscitation: definitions, current practice, and knowledge gaps. Shock. 2014;41(Suppl 1):3–12.
12. Kirkpatrick AW, Campbell MR, Jones JA, Broderick TJ, Ball CG, McBeth PB, McSway NE, Hamilton DR, Holcomb JB. Extratrrestrial hemorrhage control: terrestrial developments in technique, technology, and philosophy with applicability to traumatic hemorrhage control in long-duration space-flight. J Am Coll Surg. 2005;200:64–76.
13. Fisherman SA, Van de Velde K, Safar P, Morioka T, Obritst W, Corne L, Buckman RF, Rubertsson S, Stephenson HE, Grenvik A, et al. Future directions for resuscitation research. V. Ultra-advanced life support. Resuscitation. 1997;34:281–293.
14. Zachariah R, Bienvenue B, Ayada I, Manzi M, Maalim A,Engy E, Jenny JP, Ibrahim Said A, Hassan A, Abdulrahman F, et al. Practicing medicine without borders: tele-consultations and tele-mentoring for improving paciﬁc medicine in a conﬂict setting in Somalia? Traum. Med Int Health. 2012;17:1156–1162.
15. Pian L, Gillman LM, McBeth PB, Xiao Z, Ball CG, Blaivas M, Hamilton DR, Kirkpatrick AW. Potential Use of Remote Telesonography as a Transformational Technology in Underresourced and/or Remote Settings. Emerg Med Int. 2013;2013:986160.
16. Kirkpatrick AW, Blaivas M, Sargsyan AE, McBeth PB, Patel C, Xiao Z, Pian L, Panebianco N, Hamilton DR, Ball CG, et al. Enabling the mission through trans-Atlantic remote mentored musculoskeletal ultrasound: case report of a portable hand-carried tele-ultrasound system for medical relief missions. Telemed J E Health. 2013;19:530–534.
17. Crawford I, McBeth PB, Michelson M, Tiruta C, Ferguson J, Kirkpatrick AW. Telementorable “just-in-time” lung ultrasound on an iPhone. J Emerg Trauma Shock. 2011;4:526–527.
18. McBeth P, Crawford I, Tiruta C, Xiao Z, Zhu GQ, Shuster M, Sewell L, Panebianco N, Lautner D, Nicolau S, et al. Help is in your pocket: the potential accuracy of smartphone- and laptop-based remotely guided resuscitative telesonography. Telemed J E Health. 2013;19:924–930.
19. McBeth PB, Crawford I, Blaivas M, Hamilton T, Musselwhite K, Panebianco N, Melhuiker L, Ball CG, Gargani L, Gherdovich C, et al. Simple, almost anywhere, with almost anyone: remote low-cost telementored resuscitative lung ultrasound. J Trauma. 2011;71:1528–1535.
20. Finke EM, Padalka G, Lee D, van Holsbeeck M, Sargsyan AE, Hamilton DR, Martin D, Melton SL, McFarlin K, Dulchavsky SA. Evaluation of shoulder integrity in space: first report of musculoskeletal US on the International Space Station. Radiology. 2005;234:319–322.
21. Sargsyan AE, Hamilton DR, Jones JA, Melton S, Whitson PA, Kirkpatrick AW, Martin D, Dulchavsky SA. FAST at MACH 20: clinical ultrasound aboard the International Space Station. J Trauma. 2005;58:35–39.
22. Ponsky TA, Bobanga ID, Schwachter M, Stathos TH, Rosen M, Parry R, Nalugo M, Rothenberg SS. Transcontinental telementoring with pediatric surgeons: proof of concept and technical considerations. Adv Surg Tech A. 2013:2013:986160.
23. Rosser JC, Wood M, Payne JH, Fullum TM, Lisehora GB, Rosser LE, Barcia PJ, Savalgi RS. Telementoring. A practical option in surgical training. Adv Surg Clin North Am. 2013;17:526–527.
24. Hoang TN, Kang J, Laporta VI, Chalut C. Filling in the gaps of shoulder integrity in space: first report of musculoskeletal US on the International Space Station. Radiology. 2005;234:319–322.
25. Pannell D, Brisebois R, Talbot M, Trottier V, Clement J, Garraway N, McAlaster V, Tien HC. Causes of death in Canadian Forces members deployed to Afghanistan and implications on tactical combat casualty care provision. J Trauma. 2011;71:5401–5407.
26. Gerhardt RT, Berry JA, Blackbourne LH. Analysis of life-saving interventions performed by out-of-hospital combat medical personnel. *J Trauma*. 2011;71:S109–S113.

27. Jaffer U, Vaughan-Huxley E, Standfield N, John NW. Medical mentoring via the evolving world wide web. *J Surg Educ*. 2013;70:121–128.

28. Miller JA, Kwon DS, Dkeidek A, Yew M, Hisham Abdullah A, Walz MK, Perrier ND. Safe introduction of a new surgical technique: remote telementoring for posterior retroperitoneoscopic adrenalectomy. *ANZ J Surg*. 2012;82:813–816.

29. Chaudery M, Clark J, Wilson MH, Bew D, Yang GZ, Darzi A. Traumatic intra-abdominal hemorrhage control: has current technology tipped the balance toward a role for prehospital intervention? *J Trauma Acute Care Surg*. 2015;78:153–163.

30. Rago A, Duggan MJ, Marini J, Beagle J, Velmahos G, De Moya MA, Sharma U, Hwabejire J, King DR. Self-expanding foam improves survival following a lethal, exsanguinating iliac artery injury. *J Trauma Acute Care Surg*. 2014;77:619–623.

31. Peev MP, Rago A, Hwabejire JO, Duggan MJ, Beagle J, Marini J, Zugates G, Busold R, Freyman T, Velmahos GS, et al. Self-expanding foam for prehospital treatment of severe intra-abdominal hemorrhage: dose finding study. *J Trauma Acute Care Surg*. 2014;76:347–353.

32. Duggan MJ, Rago A, Marini J, Beagle J, Peev M, Velmahos G, Sharma U, King DR. Development of a lethal, closed-abdomen, arterial hemorrhage model in noncoagulopathic swine. *J Surg Res*. 2014;187:536–541.

33. Morrison JJ, Percival TJ, Markov NP, Villamaria C, Scott DJ, Saches KA, Spencer JR, Rasmussen TE. Aortic balloon occlusion is effective in controlling pelvic hemorrhage. *J Surg Res*. 2012;177:341–347.

34. Morrison JJ, Ross JD, Rasmussen TE, Midwinter MJ, Jansen JO. Resuscitative endovascular balloon occlusion of the aorta: a gap analysis of severely injured UK combat casualties. *Shock*. 2014;41:388–393.

35. Houckens B. System for the management of trauma and emergency surgery in space: final report. Houston, Texas; 1983 1983.

36. Kirkpatrick AW, Ball CG, Campbell M, Williams DR, Parazynski SE, Mattox KL, Broeker TJ. Severe traumatic injury during long duration spaceflight: light years beyond ATLS. *J Trauma Manag Outcomes*. 2009;3:4.

37. Crawford I, McBeth PB, Mitchelson M, Fergusen J, Tiruta C, Kirkpatrick AW. How to set up a low cost tele-ultrasound capable videoconferencing system with wide applicability. *Crit Ultrasound J*. 2012;4:13.

38. Budrionis A, Augustad KM, Patel HR, Bellika JG. An evaluation framework for defining the contributions of telestration in surgical telementoring. *Interact J Med Res*. 2013;2:c14.

39. Carenzo L, Barra FL, Ingrassia PL, Colombo D, Costa A, Della Corte F. Disaster medicine through Google Glass. *Eur J Emerg Med*. 2015;22:222–225.