Robotically applied hemostatic clamping for care-under-fire: harnessing bomb robots for hemorrhage control

Andrew W. Kirkpatrick, MD, MHSc
Ian A. McKee
Brian Knudsen
Ryan Shelton
Anthony J. LaPorta, MD
Juan Wachs, PhD
Jessica L. McKee, MSc

Accepted Apr. 7, 2021

Correspondence to:
A.W. Kirkpatrick
Regional Trauma Services
Foothills Medical Centre
Calgary, AB T2N 2T9
andrew.kirkpatrick@ahs.ca

Cite as: *Can J Surg* 2022 April 1; 65(2).
doi: 10.1503/cjs.009920

Background: Early hemorrhage control after interpersonal violence is the most urgent requirement to preserve life and is now recognized as a responsibility of law enforcement. Although earlier entry of first responders is advocated, many shooting scenes remain unsafe for humans, necessitating first responses conducted by robots. Thus, robotic hemorrhage control warrants study as a care-under-fire treatment option.

Methods: Two bomb disposal robots (Wolverine and Dragon Runner) were retrofitted with hemostatic wound clamps. The robots' ability to apply a wound clamp to a simulated extremity exsanguination while controlled by 4 experienced operators was tested. The operators were randomly assigned to perform 10 trials using 1 robot each. A third surveillance robot (Stair Climber) provided further visualization for the operators. We assessed the success rate of the application of the wound clamp to the simulated wound, the time to application of the wound clamp and the amount of fluid loss. We also assessed the operators' efforts to apply the wound clamp after an initial attempt was unsuccessful or after the wound clamp was dropped.

Results: Remote robotic application of a wound clamp was demonstrated to be feasible, with complete cessation of simulated bleeding in 60% of applications. This finding was consistent across all operators and both robots. There was no difference in the success rates with the 2 robots ($p = 1.00$). However, there were differences in fluid loss ($p = 0.004$) and application time ($p < 0.001$), with the larger (Wolverine) robot being faster and losing less fluid.

Conclusion: Law enforcement tactical robots were consistently able to provide partial to complete hemorrhage control in a simulated extremity exsanguination. Consideration should be given to using this approach in care-under-fire and care-behind-the-barricade scenarios as well as further developing the technology and doctrine for robotic hemorrhage control.

Contexte : Le contrôle précoce d'une hémorragie après un acte de violence interpersonnelle est la condition la plus urgente pour préserver la vie et est désormais considéré comme une responsabilité des forces de l'ordre. Une intervention plus précoce des premiers répondants est donc préconisée, mais comme de nombreuses scènes de fusillade sont trop dangereuses pour les humains, on utilise des robots. Par conséquent, le contrôle robotique des hémorragies mérite d'être étudié en tant qu'option de traitement sous les tirs.

Méthodes : Deux robots de neutralisation d'explosifs (Wolverine et Dragon Runner) ont été munis de clamps hémostatiques. La capacité des robots — contrôlés par 4 opérateurs expérimentés — à appliquer un clamp sur une exsanguination de membre simulée a été testée. Les opérateurs étaient affectés au hasard pour effectuer 10 essais à l'aide d'un robot chacun. Un troisième robot « de surveillance » (Stair Climber) leur procurait une vue supplémentaire. Nous avons évalué le taux de réussite de l'application du clamp sur la plaie simulée, le délai d'application du clamp et la quantité de liquide perdu. Nous avons également évalué les efforts déployés par les opérateurs pour appliquer le clamp après une première tentative infructueuse ou après la chute d'un clamp.

Résultats : Il a été conclu que l'application robotique de clamp à distance était faisable, un arrêt complet du saignement simulé ayant été obtenu dans 60 % des applications. Cette conclusion s'est avérée pour tous les opérateurs et les 2 robots. Il n'y a eu aucune différence sur le plan du taux de réussite des 2 robots ($p = 1,00$). Cependant, des différences ont été observées au chapitre de la perte de liquide ($p = 0,004$) et du délai d'application ($p < 0,001$), une plus grande rapidité et une perte de liquide moindre ayant été enregistrées pour le plus grand robot (Wolverine).

Conclusion : Les robots tactiques des forces de l'ordre ont été systématiquement en mesure d'offrir un contrôle partiel ou complet des hémorragies lors de simulations d'exsanguination de membre. Il faudrait envisager d'utiliser cette approche dans des situations critiques dangereuses, et de favoriser le développement des technologies et de la théorie du contrôle robotique des hémorragies.

Although primary prevention of mass shootings would be a laudable goal, these incidents continue to occur frequently and they represent a potential threat to the life of every citizen where firearms exist.[1,2] Exsanguination is the main cause of potentially preventable death subsequent to such interpersonal violence, and many of these deaths might be effectively prevented with simple life-saving measures if first responders could reach the victims.[3] The tragedy of a person dying from a potentially survivable injury because of a delayed medical response led to the Hartford Consensus, a set of recommendations that include a call for an integrated active shooter response denoted by the acronym THREAT: threat suppression, hemorrhage control, rapid extraction, assessment by medical providers and transport to definitive care.[4,5] A critical part of this approach involves fire and rescue services, emergency medical services (EMS) and law enforcement agencies working together to enter these scenes of interpersonal violence earlier than they have traditionally done.[1,4] If the threat remains active, however (active shooter scenario), and a zone remains "hot" rather than "warm" or secure,[5] then no human responder may attend to victims with potentially survivable injuries. Thus, any method of mitigating hemorrhage in these settings, which may be known as medicine across the barricade, may be potentially lifesaving and should be pursued.

In such situations, the initial scene entry will be robotic, using 1 or more law enforcement robots with various capabilities including surveillance, communication or ordinance disposal, or even the capability to neutralize a threat.[6] However, we are unaware of a robot ever being used nor studies being conducted to examine robot-administered hemorrhage control. We thus undertook a demonstrative study to explore the potential of robotic hemorrhage control using bomb disposal robots, which were adapted to accommodate a commercial off-the-shelf wound clamp.

Methods

This full report expands upon a previous brief report of the concept intended for rapid dissemination of what the authors perceived to be an important public safety message.[7] A custom-designed model of extremity exsanguination (Sawbones 1534 Arm Trainer, Pacific Research Laboratories Inc.) was used to demonstrate the concept of robotic wound clamping (Figure 1). The Sawbones simulator was used to simulate an arterial hemorrhage with the pulsatile loss of coloured water simulating blood loss at 2.1 mL/s. A commercially available wound clamp (iTClamp, Innovative Trauma Care) was retrofitted to 2 bomb disposal robots with fundamentally different design configurations. The iTClamp reapproximates wound edges with 4 pairs of opposing needles. This mechanism of action has been demonstrated to be safe for both the patient and the provider and has been endorsed by the Committee on Tactical Combat Casualty Care for hemorrhage control in craniomaxillofacial injuries and penetrating neck injuries with external hemorrhage.[8] The iTClamp is also approved by the US Food and Drug Administration for use on multiple sites and works in all compressible areas, including on large and irregular lacerations.[8]

One of the bomb disposal robots was a heavy-duty, outdoor, all-terrain workhorse robot (Wolverine, Northrop Grumman Remotec), designed to provide situational awareness, safety and support for reconnaissance, security, inspection and improvised explosive device missions. The Wolverine manipulator arm has 7 degrees of freedom, is 127 cm in length, weighs 544 kg and has a range of 1.5 km. The Wolverine can be controlled through fibre-optic cable and deployed from the vehicle wirelessly or through a hard tether cable.

The second robot tested was a small, lightweight, agile police robot (Dragon Runner 20, QinetiQ North America), also designed to provide situational awareness, safety and support for reconnaissance, security, inspection and improvised explosive device missions. The Dragon Runner is $42 \times 31 \times 15$ cm^3 in size, weighs 9 kg, can travel up to 6.4 km/h, can lift a maximum of 4.5 kg and has a maximum range of 650 m.

In general, the Wolverine and Dragon Runner are intended for similar purposes. The Wolverine is better suited for all-terrain applications, whereas the Dragon Runner is better able to fit into small areas.

The tests were conducted by public safety bomb technicians who were physically separated from the site of bleeding. Improved visualization of the wound was provided by the use of a lightweight surveillance robot (Vantage Patrol robot, Transcend Robotics), which provided an additional angle of view from the viewpoint different from that of either the Wolverine or Dragon Runner robots to assist the officers.

Four public safety bomb technicians from the Arapahoe County Sheriff's Office attempted to mitigate or ideally completely control simulated extremity exsanguination by robotically applying the wound clamp to seal the wound (Figure 2 and Figure 3). The operators were randomly assigned to use either the Wolverine or the Dragon Runner (2 operators were assigned to each robot, but each operator used the robot alone), and each operator applied 10 iTClamps using their designated robot only. The operators were all men, with an average age of 42.2 years (standard deviation [SD] 9.0 yr). They had an average of 9.3 (SD 7.5) years' experience. The most experienced operator had 18 years on the job while the least experienced had 3 years.

Accuracy of wound clamp application was assessed through the use of a standardized scoring protocol to assess the physical contact of the clamp with the wound (Table 1).

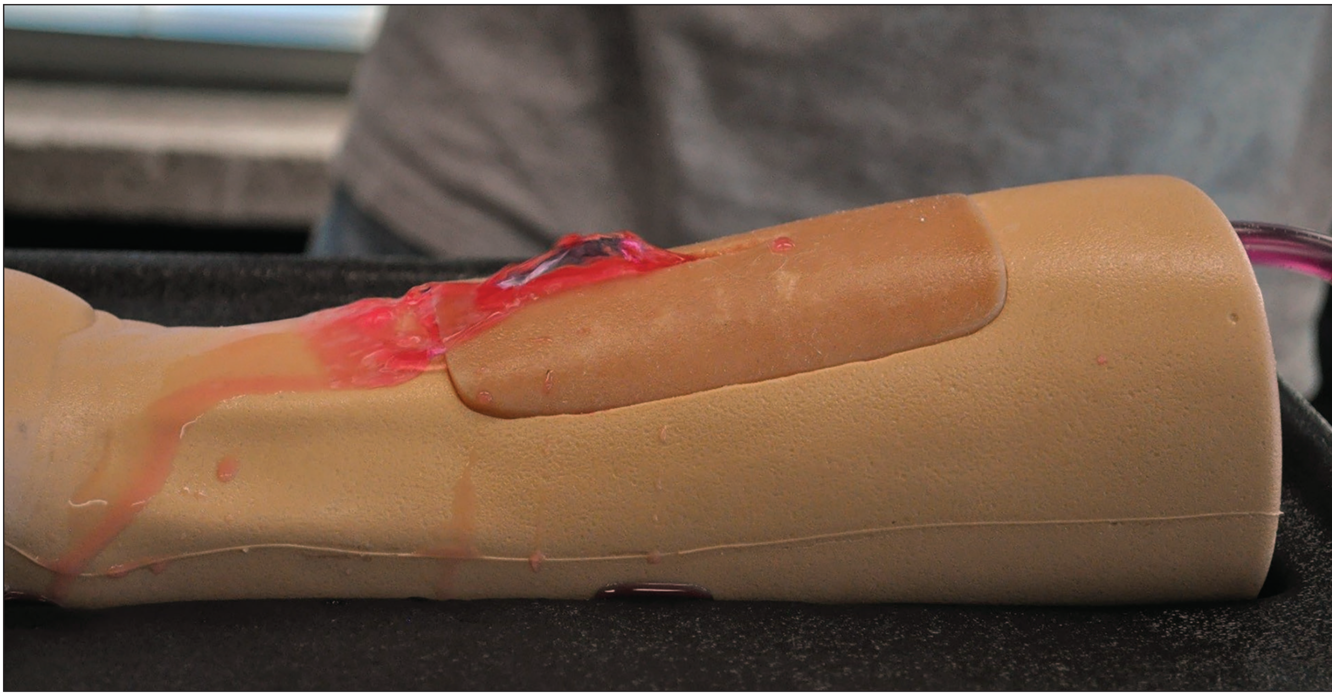

Fig. 1: Sawbones extremity exsanguination simulator (Sawbones 1534 Arm Trainer, Pacific Research Laboratories Inc.).

The effectiveness of the clamp application was assessed through the use of a standardized scoring protocol to assess the effectiveness of clamp application in controlling fluid loss from the wound (Table 2). An attempt was deemed to be unsuccessful if either the wound was completely missed or the iTClamp was applied to the wound but bleeding was not controlled at all. There were no time limitations placed upon the robot operators although time to application was measured as a study variable. There was no penalty for "dropped" wound clamps other than the additional time taken to complete the testing sequence. Repeated applications following any initial application were permitted at the complete discretion of the robot operator. For the discussion of potential operational relevance, zones of potential threat were defined according to Pennardt, with the term "hot zones" describing the area where a direct and immediate threat exists and the term "warm zones" specifically referring to the area where a potential threat exists but where there is no direct or immediate threat.[5]

Results

This investigation demonstrated that remote-controlled robots were able to effectively apply wound clamping to a simulated sanguinating extremity wound to completely control fluid loss.

Wolverine robot

Two separate operators who used the Wolverine robot to apply a total of 20 wound clamps required a median time of 63.5 (interquartile range [IQR] 35.0) seconds to complete the task. The median fluid loss was 137.5 (IQR 69.0) mL. The operators managed to apply the wound clamp successfully 60% (n = 12) of the time, meaning that bleeding had completely stopped or there was only minimal leakage. In 40% (n = 8) of cases the application was deemed not successful. The wound clamp was dropped once during the study; the operator was able to pick up the wound clamp again with the robot and apply it to the wound successfully. This case took 90 seconds and 175 mL of blood was lost. When we compared the successful and unsuccessful applications of the wound clamp, there was no difference in time (p = 0.62) or fluid loss (p = 0.91). The 2 operators differed significantly in terms of time (p = 0.004) and fluid loss (p = 0.003) but not success rate (p = 1.000) (Table 3).

Dragon Runner robot

Using the smaller robot (Dragon Runner), 2 operators applied a total of 20 iTClamps (10 each) (Table 3). The median application time was 121.0 (IQR 85.0) seconds. The median fluid loss was 225.0 (IQR 175) mL. Similar to the results with the Wolverine robot, the operators of the Dragon Runner robot had a 60% (n = 12) success rate for wound clamp applications. There was no difference in application time between successful and unsuccessful applications (p = 0.68) or between operators (p = 0.32). Likewise, there was no difference in fluid loss between successful and unsuccessful applications (p = 0.97) or between operators (p = 0.06), and there was no difference (p = 1.00) in the success rates of the operators.

Fig. 2: Overview of the Dragon Runner robot about to apply the wound clamp to the Extremity Exsanguination model with the Vantage Patrol robot observing. The Vantage Patrol robot provided triangulation for increased visualization at a right angle to the Dragon Runner robot.

Comparative performance of the Wolverine and Dragon Runner robots

The success rates of wound clamp application did not differ between the Wolverine and the Dragon Runner (p = 1.00). However, there was significantly less fluid loss (p = 0.004) and a significantly shorter application time (p < 0.001) with the Wolverine (Table 4). When we examined the success rate for the 2 robots combined, there was no difference in time (p = 0.72) or fluid loss (p = 0.75) between the successful and unsuccessful attempts.

Discussion

In this assessment of bomb disposal robots with very different design features and specialized capabilities, it became apparent that they both offer a nonhuman robotic potential to administer point-of-care hemorrhage control. Most notably, they offer a potential hemorrhage control option in care-under-fire situations that would be lethal to human first responders. Both robots were able to apply a hemostatic wound clamp under remote control in the majority (60%) of attempts.

These early proof-of-concept studies were not designed to actually compare different robots or operators, just to test the concept. Attributes of the Wolverine were its large platform and its ability to provide a bird's eye view with a high camera mast and several other camera systems that provide the operator with different pictures to look at when applying the clamp. The strength of the claw of the Wolverine to apply the clamp tightly was also perceived as an advantage. The Dragon Runner

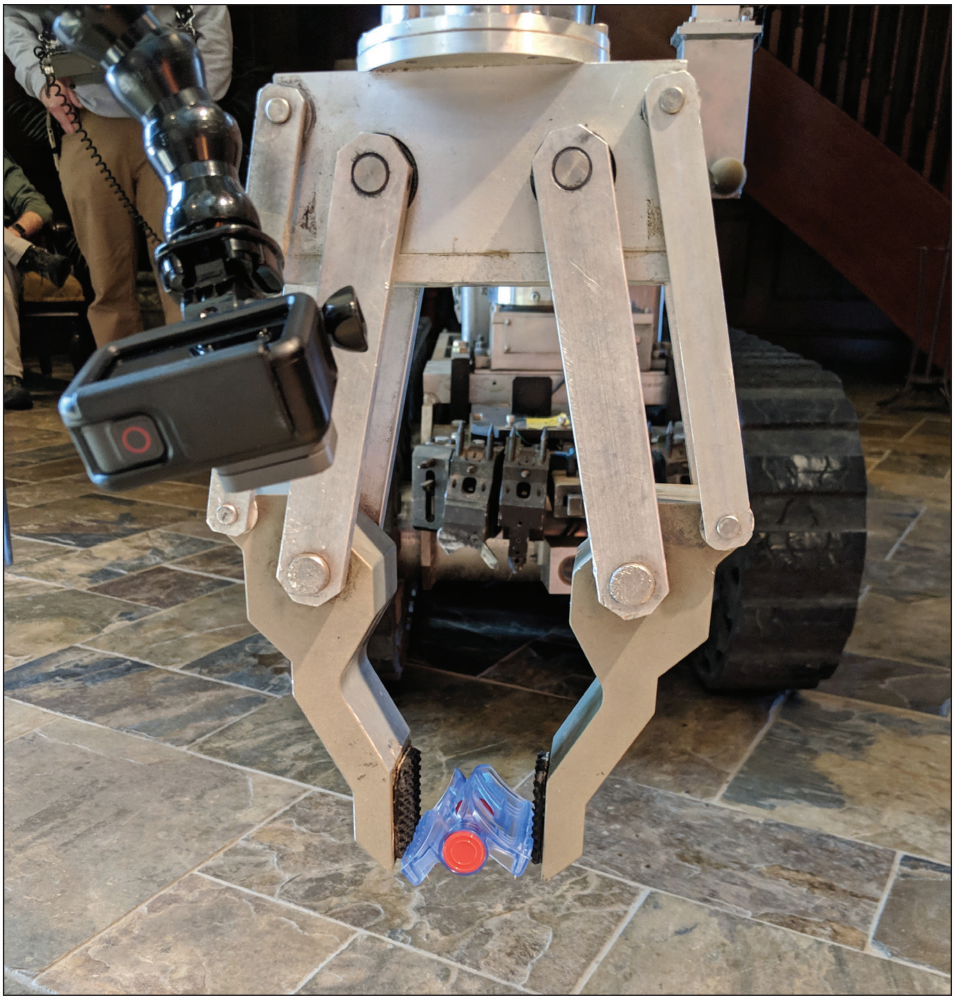

Fig. 3: Wolverine robot equipped with wound clamp in its manipulator.

Table 1. Standardized scoring protocol to assess the physical contact of the clamp with the wound

Category	Description
Misapplication	There is no physical contact between the tissue wound and the wound clamp.
Partial application	There is partial physical contact between the wound clamp and the tissue wound such that the wound clamp is secured to the tissue.
Complete application	There is physical contact between the wound clamp and the tissue wound such that the tissue wound is completely encompassed within the teeth of the clamp.
Dropped application	There is complete physical separation of the clamp from the robot without sustained contact with the tissue wound.
Repeated application	The robot operator chooses to reapply the wound clamp to the wound tissue after any type of prior application (misapplication or partial, complete or dropped application). This category applies in this situation regardless of whether the subsequent application is more effective or not.

Table 2. Standardized scoring protocol to assess the effectiveness of wound clamp application in controlling fluid loss from the wound

Category	Description
Ineffective hemorrhage control	No mitigation of pulsatile "bleeding"*
Partial hemorrhage control	Mitigation of pulsatile "bleeding"* so that it becomes nonpulsatile
Marked hemorrhage control	Conversion of pulsatile "bleeding"* to "oozing" as a trickle of fluid loss
Complete hemorrhage control	Complete cessation of any fluid loss from the tissue wound

*"Bleeding" refers to the loss of coloured water through the use of a hydrostatic pump; it should be noted that water has no procoagulant or hemostatic properties.

Table 3. Application time, fluid loss and success rate by robot and operator									
Robot and technician	Technician's age, yr	Technician's experience, yr	No. of iTClamps	Application time, s, median (IQR)	*p* value	Fluid loss, mL, median (IQR)	*p* value	Successful applications, no. (%)	*p* value
Wolverine									
Technician 1	35	3	10	49.5 (57.0)	0.004	125.0 (25.0)	0.003	6 (60)	1.00
Technician 2	54	18	10	76.5 (33.0)		162.5 (50.0)		6 (60)	
Dragon Runner									
Technician 3	35	3	10	122.5 (61.0)	0.325	250.0 (81.0)	0.06	6 (60)	1.00
Technician 4	43	13	10	101.0 (123.0)		137.5 (200.0)		6 (60)	

IQR = interquartile range.

Table 4. Application time, fluid loss and success rate by robot							
Robot	No. of iTClamps	Application time, s mean ± SD	*p* value	Fluid loss, mL, mean ± SD	*p* value	No. of successful applications	*p* value
Wolverine	20	60.8 ± 29.9	< 0.001	145.0 ± 39.4	0.004	12	1.00
Dragon Runner	20	133.1 ± 39.4		213.8 ± 93.0		12	

SD = standard deviation.

appeared to be better suited to situations where patients are in a more confined space; however, it was perceived to be more likely to require an additional robot to provide supplementary camera views to ensure the clamp is being applied appropriately.

None of the operators had any prior experience in robotic hemorrhage control, nor had they ever seen the extremity hemorrhage simulator or wound clamp before. This reflects the current operational status of robotic hemorrhage control. But even a partially successful wound clamp application might be clinically beneficial as some hemorrhage control is better than none. We strongly suspect and predict that as robotic hemorrhage control becomes accepted as a core capability of law enforcement, the skills and performance in this arena will dramatically improve as highly motivated people train to provide this service.

It is no longer acceptable to delay applying hemorrhage control to patients who experience penetrating trauma until the scene of a hostile incident is secured if the risks of responding can be managed or mitigated. Methods of managing these risks include creating semi-protected and defended warm zones and entry and egress corridors. The recommendations that arose from the Hartford Consensus meeting and subsequent consensus statements have recognized both the opportunity and the responsibility of law enforcement personnel to respond to and address active hemorrhage before the arrival of EMS personnel.[1,4,9] Hemorrhage, especially extremity hemorrhage, is often readily treated, but it must be treated without delay, as an arterial hemorrhage that might be survivable if controlled early may progress to irreversible shock and death as exsanguination occurs. However, one of the basic tenets of effective care under fire is to avoid unnecessary secondary causalities, which will only complicate further rescue efforts and doom the original primary patient. It is a devious but common tactic for perpetrators of firearms violence to target such responding potential caregivers.[10,11] It should be obvious that EMS providers need to avoid becoming patients rather than caregivers.

The role of robots and drones is rapidly expanding. Law enforcement robots have been used to neutralize active shooters through both lethal and nonlethal methods as well as to deliver food and communications devices.[6] We are not aware of any instances of robotic hemorrhage control being delivered but speculate that if effort and resources are dedicated to pursuing robotic hemorrhage control, technologies could develop rapidly.

The concept of using robots to apply wound clamps was initially reported using a proof-of-concept low-cost robot with limited power and degrees of freedom yet capable of deploying a hemostatic wound clamp that was constructed and effectively and consistently deployed on a simulated extremity wound using low-cost off-the-shelf technologies.[12] The study reported herein represents a marked augmentation in robotic sophistication using industry-standard robots. The wound clamp used in this experiment was the ITClamp, which has demonstrated effectiveness in animal models of junctional hemorrhage,[13,14] can be used to expedite chest tube fixation,[15] can be used in laparotomy closure[16] and potentially maintains limb function.[17] This device appears to be attractive for robotic hemorrhage control because of its simplicity. A theoretical limitation, however, is expanding hematoma within the depths of a wound, for which packing would ideally be introduced before wound clamping.[14]

Although not all extremity wounds such as traumatic amputations will be completely controlled with a wound clamp, many will be, and wound clamping will better preserve residual limb function if this limb is required for self-extrication or defence.[8,9] In the future, first-responding bomb disposal robots might be equipped with further hemorrhage control capabilities such as wound packing materials[18,19] or hemostatic foam sealants,[20] which could be held in place by a wound clamp rather than a human hand.[21] If we speculate further into the future, ultrasonography, which is a universally valuable telementorable imaging technology, could be performed robotically as well. Some initial studies have been conducted regarding remote robotic imaging,[22,23] and it can be used to both accurately localize arterial hemorrhage and pinpoint physical compression for hemorrhage control.[24]

Thus, retrofitting bomb disposal robots to place wound clamps may be an initial and immediately practical step toward the delivery of a practical "trauma-pod" capability that was long envisioned as a robotic hemorrhage control solution for futuristic military operations.[25] However, as public safety bomb technicians would never be expected to make go/no-go decisions regarding robotic hemorrhage control attempts, it would be beneficial to have virtual telemedical medical oversight with teams of subject matter experts[26] liaising in real time with law enforcement personnel during robotic first responses to hot-zone patients, to balance the rescue versus immediate resuscitation needs of these patients.

Limitations

Limitations of this study include the just-in-time nature of the public safety bomb technicians' exposure to the task: they were required to learn "on the job" when asked to apply the wound clamp. This scenario thus precluded any rehearsal or practice, which would certainly be expected to improve performance with either robot in the future. It is logical to expect that there would be a learning curve, with the operators becoming quicker and more accurate with formal training and experience. Given the nature of law enforcement personnel, a good-natured competitive spirit could be expected to catalyze performance improvements. However, given the modest number of operators in this evaluation, which closely links individual operator performance to robotic outcome, conclusions should not be drawn regarding which operator or robot was "best," other than that all were successful at the task and substantial improvements in performance in the future would be predicted. As this is 1 emerging capability among many that a bomb robot must provide, the decision about which robot to use in a given situation would reside with the law enforcement community (specifically the bomb disposal community), not the surgical community. A further limitation was the use of an exsanguination simulator that used water as the test fluid and a pulsatile but still artificial pump. Given that water does not have any intrinsic coagulative properties and the similuator did not replicate the normal arterial pulsatile flow of humans, hemostasis was not realistically recreated.[27] However, this can be considered a conservative bias, as it would be harder to achieve cessation of "bleeding" than with human wounds in human tissue. There was also no statistically significant difference in the overall application time or fluid loss between operators or between robots. This was a function of the study methodology wherein the scenario ended when the public safety bomb technician felt they had completed the task of wound clamping. In future attempts to elucidate the superiority of different techniques or robots, the bleeding after wound clamping and casualty extraction might be superior outcome measures.

Conclusion

Existing bomb disposal robots have the capability to provide remotely controlled hemorrhage control through applying wound clamps to simulated extremity wounds. Given the frequent occurrence of interpersonal violent traumatic injury and potentially preventable exsanguination deaths in modern society, we suggest that it behooves all involved in first responses to consider adding an earlier robotic hemorrhage control option to active shooter responses. Further robotic hemorrhage control appears to be an undeveloped technical need in the modern world, for which further development of the technology, logistics and protocols to advance prehospital hemorrhage control should be actively pursued.

Affiliations: TeleMedical Ultrasound Supported Medical Interventions (TMUSMI) Research Group, Departments of Surgery (Kirkpatrick, J.L. McKee) and Critical Care Medicine (Kirkpatrick), and the Trauma Service (Kirkpatrick, J.L. McKee), Foothills Medical Centre (Kirkpatrick, J.L. McKee), Calgary, Alta.; Canadian Forces Medical Services (Kirkpatrick); Edmonton Fire Department (I. McKee), Edmonton, Alta.; Arapahoe County Sheriff's Office (Knudsen), Centennial, Colo.; South Metro Fire Rescue (Shelton), Denver, Colo.; Rocky Vista School of Medicine (LaPorta), Parker, Colo.; Purdue University (Wachs), West Lafayette, Ind.

Funding: This work was partially supported by a Near Earth Space Technologies Grant from the University of Calgary.

Competing interests: A. Kirkpatrick is the principal investigator of the COOL trial (https://clinicaltrials.gov/ct2/show/NCT03163095), with partial unrestricted funding from Acelity. He has also consulted for Innovative Trauma Care, Zoll Medical, CSL Behring and SAM Medical Products. J. McKee is a contract employee of Innovative Trauma Care and has done contract work for Aceso, SAM Medical Products, Acelity, Zoll Medical and the Andrew W. Kirkpatrick Professional Corporation. A. Kirkpatrick and J. McKee disclose a personal relationship. I. McKee and J. McKee disclose a personal relationship. No other competing interests were declared.

Contributors: A. Kirkpatrick and J. McKee designed the study. A. Kirkpatrick, I. McKee, B. Knudsen, R. Shelton, A. LaPorta and J. McKee acquired the data, which A. Kirkpatrick, J. Wachs and J. McKee analyzed. A. Kirkpatrick, I. McKee and J. McKee wrote the article, which A. Kirkpatrick, B. Knudsen, R. Shelton, A. LaPorta, J. Wachs and J. McKee critically revised. All authors gave final approval of the version to be published.

Disclaimer: The opinions expressed in this article are solely those of the authors and do not represent official policies or doctrine of any agency of the governments of Canada or the United States of America.

References

1. Pons PT, Jerome J, McMullen J, et al. The Hartford Consensus on active shooters: implementing the continuum of prehospital trauma response. *J Emerg Med* 2015;49:878-85.
2. Dickinson A, Roberts M, Kumar A, et al. Falls from height: injury and mortality. *J R Army Med Corps* 2012;158:123-7.
3. Goolsby C, Rouse E, Rojas L, et al. Post-mortem evaluation of potentially survivable hemorrhagic death in a civilian population. *J Am Coll Surg* 2018;227:502-6.
4. Jacobs LM, McSwain NE Jr, Rotondo MF, et al. Improving survival from active shooter events: the Hartford Consensus. *J Trauma Acute Care Surg* 2013;74:1399-400.
5. Pennardt A Sr. Hot, warm, and cold zones: applying existing national incident management system terminology to enhance tactical emergency medical support interoperability. *J Spec Oper Med* 2014;14:78-9.
6. Weisberger M. 'Bomb robot' kills Dallas shooter: how police did it. *Live Science* 2016 July 8. Available: www.livescience.com/55331-dallas-shooting-bomb-robot.html (accessed 2016 Jul. 8).
7. McKee IA, McKee JL, Knudsen BE, et al. A "human-proof pointy-end": a robotically applied hemostatic clamp for care-under-fire. *Can J Surg* 2019;62:E13-5.
8. Onifer DJ, McKee JL, Faudree LK, et al. Management of hemorrhage from craniomaxillofacial injuries and penetrating neck injury in tactical combat casualty care: iTClamp mechanical wound closure device TCCC guidelines proposed change 19-04 06 June 2019. *J Spec Oper Med* 2019;19:31-44.
9. Jacobs LM, Wade D, McSwain NE, et al. Hartford Consensus: a call to action for THREAT, a medical disaster preparedness concept. *J Am Coll Surg* 2014;218:467-75.
10. Schouten R, Brennan DV. Targeted violence against law enforcement officers. *Behav Sci Law* 2016;34:608-21.
11. Crifasi CK, Pollack KM, Webster DW. Assaults against U.S. law enforcement officers in the line-of-duty: situational context and predictors of lethality. *Inj Epidemiol* 2016;3:29.
12. Kirkpatrick AW, McKee JL, McKee I, et al. A "human-proof pointy end" for a potential trauma pod effector: technical notes on robotically applied hemostatic applied clamp for care under fire: an update. *Can J Surg* 2018;61(Suppl):S14.
13. Filips D, Logsetty S, Tan J, et al. The iTClamp controls junctional bleeding in a lethal swine exsanguination model. *Prehosp Emerg Care* 2013;17:526-32.
14. St John AE, Wang X, Lim EB, et al. Effects of rapid wound sealing on survival and blood loss in a swine model of lethal junctional arterial hemorrhage. *J Trauma Acute Care Surg* 2015;79:256-62.
15. McKee JL, McKee I, Bouclin M, et al. Use of the iTClamp versus standard suturing techniques for securing chest tubes: a randomized controlled cadaver study. *Turk J Emerg Med* 2018;18:15-19.
16. Kirkpatrick AW, McKee JL, Tien CH, et al. Abbreviated closure for remote damage control laparotomy in extreme environments: a randomized trial of sutures versus wound clamps comparing terrestrial and weightless conditions. *Am J Surg* 2017;213:862-9.
17. LaPorta A, Kirkpatrick AW, McKee JL, et al. Randomised controlled trial comparing marksmanship following application of a tourniquet or haemostatic clamp in healthy volunteers. *J R Army Med Corps* 2017;163:177-83.
18. Warriner Z, Lam L, Matsushima K, et al. Initial evaluation of the efficacy and safety of in-hospital expandable hemostatic minisponge use in penetrating trauma. *J Trauma Acute Care Surg* 2019;86:424-30.
19. Schauer SG, April MD, Naylor JF, et al. Prehospital application of hemostatic agents in Iraq and Afghanistan. *Prehosp Emerg Care* 2018;22:614-23.
20. Rago AP, Larentzakis A, Marini J, et al. Efficacy of a prehospital self-expanding polyurethane foam for noncompressible hemorrhage under extreme operational conditions. *J Trauma Acute Care Surg* 2015;78:324-9.
21. Stuart SM, Zarow G, Walchak A, et al. Pilot study of a novel swine model for controlling junctional hemorrhage using the iTClamp in conjunction with hemostatic agents. *Mil Med* 2019;184(Suppl 1):367-73.
22. Arbeille P, Ruiz J, Ayoub J, et al. The robot and the satellite for tele-operating echographic examination in earth isolated sites, or onboard ISS. *J Gravit Physiol* 2004;11:233-4.
23. Adams SJ, Burbridge BE, Badea A, et al. Initial experience using a telerobotic ultrasound system for adult abdominal sonography. *Can Assoc Radiol J* 2017;68:308-14.
24. Kirkpatrick AW, McKee JL, McKee I, et al. Remote telementored ultrasound-directed compression to potentially accelerate hemostasis in exsanguinating junctional vascular injuries. *J Spec Oper Med* 2015;15:71-4.
25. Garcia P, Rosen J, Kapoor C, et al. Trauma pod: a semi-automated telerobotic surgical system. *Int J Med Robot* 2009;5:136-46.
26. Kirkpatrick AW, McKee JL, Netzer I, et al. Transoceanic telementoring of tube thoracostomy insertion: a randomized controlled trial of telementored versus unmentored insertion of tube thoracostomy by military medical technicians. *Telemed J E Health* 2019;25:730-9.
27. Kirkpatrick AW, McKee JL, Tien H, et al. Damage control surgery in weightlessness: a comparative study of simulated torso hemorrhage control comparing terrestrial and weightless conditions. *J Trauma Acute Care Surg* 2017;82:392-9.