Temporizing Life-Threatening Abdominal-Pelvic Hemorrhage Using Proprietary Devices, Manual Pressure, or a Single Knee

An Integrative Review of Proximal External Aortic Compression and Even "Knee BOA"

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ABSTRACT

Introduction: Abdominal-pelvic hemorrhage (i.e., originates below the diaphragm and above the inguinal ligaments) is a major cause of death. It has diverse etiology but is typically associated with gunshot or stab wounds, high force or velocity blunt trauma, aortic rupture, and peripartum bleeds. Because there are few immediately deployable, temporizing measures, and the standard approaches such as direct pressure, hemostatics, and tourniquets are less reliable than they are with compressible extremity injuries, risk for death resulting from abdominal-pelvic hemorrhage is high. This review concerns the exciting potential of proximal external aortic compression (PEAC) as a temporizing technique for life-threatening lower abdominal-pelvic hemorrhage. PEAC can be accomplished by means of a device, two locked arms (manual), or a single knee (genicular) to press over the midline supra-umbilical abdomen. The goal is to compress the descending aorta and slow or halt downstream hemorrhage while not delaying more definitive measures such as hemostatic packing, tourniquets, endovascular balloons, and ultimately operative repair. **Methods:** Clinical review of the Ovid MEDLINE, In-Process, & Other Non-Indexed, and Google Scholar databases was performed for the period ranging from 1946 to 3 May 2019 for studies that included the following search terms: [proximal] external aortic compression OR vena cava compression AND (abdomen or pelvis) OR (hemorrhage) OR (emergency or trauma). In addition, references from included studies were assessed. **Conclusion:** Sixteen studies met the inclusion criteria. Evidence was grouped and summarized from the specialties of trauma, aortic surgery, and obstetrics to help prehospital responders and guide much-needed additional research, with the goal of decreasing the high risk for death after life-threatening abdominal-pelvic hemorrhage.

KEYWORDS: *hemorrhage; trauma; shock; junctional trauma; noncompressible hemorrhage; prehospital care; austere environment; proximal external aortic compression; PEAC*

Introduction

Optimistically, there is a growing interest in the prehospital and preoperative management of penetrating life-threatening lower abdomen, pelvic, and junctional hemorrhage.[1,2] Less optimistically, it remains the leading cause of potentially survivable death in modern conflict zones[3] and one of the leading causes of civilian traumatic exsanguination.[4] Indeed, a 2018 retrospective review of mass casualty civilian deaths after gunshot wounds (GSWs) suggested major nonextremity blood vessel trauma could be universally fatal.[5] Regardless, preoperative interventions include hemostatic gauze packing[6]; abdominal aortic and junctional tourniquets[2,7,8]; combat clamps[9]; resuscitative endovascular balloon occlusion of the aorta (REBOA)[10]; intracavity self-expanding foam; minimally invasive preperitoneal balloon tamponade[11]; and compressed hemostatic sponges.[12]

Although promising and innovative, these devices have limitations, including cost, limited kit space, the possibility of malfunction, and the need for rescuers to be initially trained and then to maintain skills.[13] Furthermore, these proprietary devices may not be available to the majority of prehospital responders or in environments where hemorrhage occurs (e.g., work sites, highways, battlefields). These devices also take time to apply, whereas exsanguination can occur in seconds. Accordingly, our review focuses on a maneuver that is simple, cost-free, easy to teach, easy to retain, and requires no additional equipment. The goal is the same as with proprietary devices, namely to indirectly prevent downstream hemorrhage by occluding, via tamponade, the aorta, and thereby gain additional time. Instead of applying a device, rescuers compress the aorta, with two locked arms (manual) or one knee (genicular) atop the supra-umbilical abdomen. This technique has been called proximal external aortic compression (PEAC). It has since gained two memorable aliases from prehospital personnel: "ghetto-reboa" and "knee-boa."

PEAC Description

After life-threatening hemorrhagic trauma, rescuers typically immediately will apply direct pressure to the wound. This is a life-sustaining first step and precedes more definitive temporization methods, such as hemostatic-gauze packing or tourniquet placement. This is often successful in extremity trauma because those body parts are easily compressible, and the

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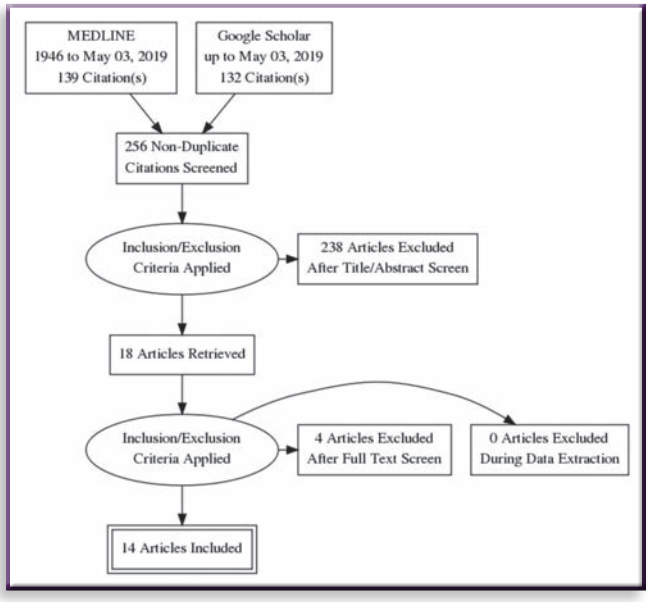
vessels are more superficial and run adjacent to long bones. In contrast, our discussion focuses on bleeding that is less amenable to direct pressure, such as abdominopelvic and junctional hemorrhage. In these latter cases, indirect pressure, or pressure that is applied over the aorta proximal to the hemorrhage can be similarly expedited. We propose that this be done with hands or a knee, and preceding more definitive temporizing measures, which can, in turn, be divided into noninvasive (e.g., tourniquet) devices or invasive (i.e., REBOA).

PEAC, whether via a device, the rescuer's hands, or the rescuer's knee, reduces or occludes distal blood flow in noncompressible regions.[14–16] The common goal is to compress the central vessels against the spinal cord and a hard surface, such as a concrete roadside or extrication board. In this article, we review the published data, with a focus on manual and genicular compression after postpartum hemorrhage (PPH), aortic rupture, and penetrating trauma. We wish to encourage PEAC as a temporizing measure in the chain of survival and to achieve the Hartford Consensus mandate: that no one should die from uncontrolled bleeding.[17]

Methods

A medical librarian conducted a search of the Ovid MEDLINE, In-Process & Other Non-Indexed Citations, and Google Scholar databases for literature dating from 1946 to 3 May 2019, using the following search terms: (external aortic compression OR proximal external aortic compression OR vena cava compression) AND (abdomen or pelvis) OR (hemorrhage) OR (emergency or trauma). A flow diagram of the search process is provided in Figure 1. In addition, references from included studies were assessed.

FIGURE 1 *Search flow diagram.*



A search of Medline returned 315,167 results for "exp Hemorrhage"; 81,233 for "(abdominal hemorrhage or abdomen or pelvis)"; 3,017 for a combination of "exp Hemorrhage" and "(abdominal hemorrhage or abdomen or pelvis)"; 139 for "(external aortic compression or proximal external aortic compression or aortic compression or external manual compression or manual external aortic compression or indirect pressure).mp," where ".mp" in the search term stands for "multipurpose"; 3,362 for (compression and (aorta or vena cava)).mp"; and 14 for a combination of "exp Hemorrhage," "(abdominal hemorrhage or abdomen or pelvis)," (external aortic compression or proximal external aortic compression or aortic compression or external manual compression or manual external aortic compression or indirect pressure).mp," and (compression and (aorta or vena cava)).mp." A search of Google Scholar returned 132 results. An additional six grey-literature articles (e.g., conference presentations, newspaper articles, textbooks, course documents, practice guidelines) were obtained via the Google search engine and two additional articles were identified through consultation with experts. Sixteen articles were included in this review. Results are described in narrative form in the specific sections that follow.

Postpartum Hemorrhage

After life-threatening peripartum hemorrhage and PPH, external aortic compression is endorsed by the World Health Organization,[18] the Advanced in Labour and Risk Management International program for emergency obstetrical care,[19] and the Queensland Ambulance Service.[20] In a 1996 study that investigated healthy postpartum volunteers, Riley and Burgess[14] reported that manual PEAC successfully arrested femoral artery pulses in 11 of 20 healthy postpartum mothers. Soltan et al.[21] performed a two-stage quasi-experimental trial of external aortic compression after PPH and compared a device (the El-Minia aortic compression device) versus aortic manual pressure. During the first period, PPH annually caused six deaths and 22–31 complications. The PPH incidence declined from 4.6% in 1999 to 0.9% at the end of the study. In 2008 and 2009, there were no deaths due to PPH and only four complications were recorded in each of these 2 years. Similar results were found with manual pressure and device aortic compression.[21] Moreover, Soltan et al.[21] established external aortic compression as an effective measure to prevent severe shock and death, second only to blood transfusions in treatment effect (20 units of blood required in 2008 using the device versus 72 units needed in 2009 using manual compression, which the authors attributed to bleeding while switching compressors; p <.001). Balanced against these positive data is a retrospective assessment of PPH treatment with and without aortic compression in which no difference was found in blood loss or time to hemorrhage control.[22]

Soltan et al.[23] also looked at Doppler velocimetry and demonstrated that femoral blood flow could be substantially reduced for longer than 2.5 hours without creating abdominal compartment syndrome or lasting lower-extremity neurovascular injury. External aortic compression devices have also been favorably reviewed by van Oostendorp et al.[1] and Smith et al.[2] At least one transport program, CareFlight Australia, uses the Abdominal Aortic and Junctional Tourniquet (Compression Works; http://compressionworks.com) for PPH (in addition to using it for trauma).[24,25] However, an extensive review of devices is outside the scope of this review.

Cardiovascular System

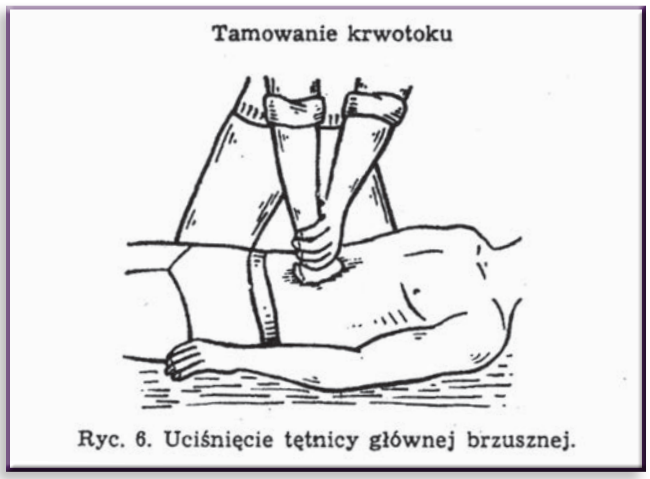
Manual PEAC was used as a temporizing measure after aortic aneurysmal rupture. Kin et al.[26] published a case report of epigastrial PEAC performed on an 83-year-old woman with a ruptured infrarenal aortic aneurysm. In their words, "with continuous external manual compression, the femoral pulse was not palpable on either side, while the radial systolic blood pressure exceeded 100mmHg within 5min of circulatory

collapse."[26] Van Roekens et al.[27] also described external aortic compression in a case of tetralogy of Fallot cyanotic crisis. This involved clinicians applying digital PEAC along with an improvised abdominal tourniquet (i.e., a circumferentially applied blood pressure cuff). The treatment was associated with an increase in arterial oxygen saturation from 19% to 35%.[28] Used as a temporizing measure, Van Roekens suggest "external manual compression of the abdominal aorta can be as effective as surgical clamping or vasopressors" and can garner valuable time to bridge patients to definitive surgical repair.[36]

Trauma

PEAC after trauma was reportedly taught to tactical providers in the 1990s to temporize inguinal hemorrhage.[28] However, the first written description may be a 1983 article in Polish on first aid hemorrhage control (Figure 2).[29] The first, written, English-language recommendation for trauma appears to be from retired consultant general surgeon Harry Espiner, in *The Guardian* newspaper. He suggested two fists, one placed above and one below penetrating abdominal wounds to control hemorrhage.[30] Our team (Douma et al.) described a peer-reviewed case report of PEAC application for a trauma patient in 2013.[15] In that case, PEAC resulted in returned consciousness of a moribund victim of multiple GSWs to the abdomen pelvic and lower limb. Notably, a heavier rescuer (>90kg) arrested bleeding, resulting in the patient regaining consciousness. Transfer of care to a lighter rescuer, as well as ambulance transfer, resulted in ineffective PEAC, clinical deterioration, and, ultimately, death.[15] An additional series of four illustrative cases have been recently published by Dr Bruce Paix et al. from Australia.[31] Furthermore, a clinical team from Montreal has demonstrated the use of an ultrasound probe to identify the aorta, compress it, and confirm that compression was effective.[32]

FIGURE 2 *External aortic compression.*
Early description of bimanual external compression of the "abdominal artery." Adapted from Badowski and Zaras.[29]



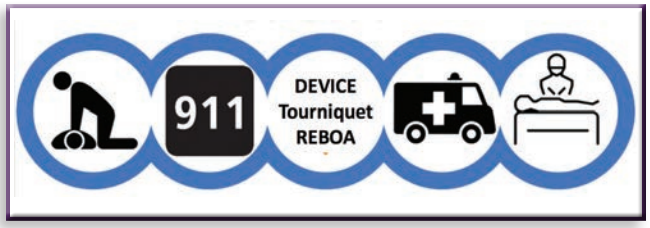
Feasibility Studies

Our 2013 case led to a comprehensive research program, including feasibility,[30] technique optimization,[33] application during transfer,[34] and ultrasound assessment in healthy volunteers.[16] We found that (perhaps intuitively) heavier rescuers compress more weight and that compression efficiency is increased by optimizing technique. Specifically, we found that one-handed compression resulted in the transmission of less than 30% of the rescuer's body weight. Compression efficiency is increased with a second hand, a hard surface beneath the victim, and by lowering the patient from waist height to floor height so rescuers are atop victims and can lock their arms.[30] With these strategies, and with maximal effort, participants could manually compress almost 70% of their body weight for approximately 2 minutes. Using a single knee, participants compressed approximately 80% of their body weight and could maintain the maximal effort for as long as 20 minutes.[33] In short, we have demonstrated that using two hands or a knee is worthwhile when there is no alternative. However, our ambalance studies[35] have demonstrated why a device or invasive intervention should decrease the likelihood of exsanguination during transfer. In other words, it is not a case of PEAC or a device, but rather PEAC until a device can be reliably applied, especially if providers are to remain with their seat belt on during ambulance or helicopter transfer.[33]

Recently, we confirmed using ultrasound that rescuers with minimal training could rapidly arrest femoral artery blood flow using bimanual PEAC.[16] Moreover, we showed that PEAC could stop femoral blood flow within 20 seconds, albeit in healthy volunteers.[16] Although our participants tolerated the compression (median pain score on a 0–10 scale: 5; range, 4–7), Soltan et al.[23] have reported greater pain in obese women and a increased pain and compression failure were reported in a junctional tourniquet trial in a participant with above-average body mass.[36]

From a practicality standpoint, we are pleased to report we have taught PEAC to more than 200 clinicians and 80 other course participants. Training is free, reliable (using instructor demonstration and student return demonstration), requires no equipment and takes less than 5 minutes. Moreover, remedial instruction is infrequently required because the bimanual technique approximates that used for cardiac chest compressions.[37] Figure 3 outlines how PEAC could be integrated into a chain of survival for life-threatening abdominal-pelvic and junctional hemorrhage (Figure 3).[34]

FIGURE 3 *Life-threatening abdominal-pelvic and junctional hemorrhage chain-of-survival.*
Proposed "chain of survival" for life-threatening abdominal-pelvic and junctional hemorrhage. Adapted from Douma et al.[34]



Proposed Role and Rationale for PEAC in Trauma

Tactical Combat Casualty Care proposes a "platinum ten minutes"[38] to highlight the importance of early temporizing control of massive hemorrhage. Recent work argues for a shorter 3-minute window.[39] After all, blood flow from a single femoral artery approximates 3L/min during stress.[40] Like us, Tjardes and Luecking[39] challenge whether a device can be reliably retrieved and applied in that brief time. In contrast, manual or genicular PEAC can be applied immediately. Junctional tourniquet application conservatively takes longer than a minute.[41] Use of REBOA in Zone 3 trauma (i.e., the area extending distally from the lowest renal artery to the aortic bifurcation) is promising, especially because it occludes femoral vessels via an

internal technique.[42] However, REBOA and other noninvasive techniques require special equipment, expertise, and, most importantly, time.

As outlined, manual or knee-PEAC can be applied immediately by any minimally trained lay rescuer and requires no equipment to be retrieved or applied. Even if not trained, it should be easy for 911 call-takers to provide bystander instruction, in the same manner as occurs with chest compressions after cardiac arrest.[43] Accordingly, we believe PEAC is a maneuver that should be used as a rapid bystander intervention or buddy rescue technique and alongside traditional hemorrhage control measures. It can fit seamlessly into broader public health measures geared toward engaging the public and first responders.[5,17]

Though PEAC (whether by device, hands, or knee) is intuitive and has likely been attempted many times, we believe it has still been insufficiently reported, studied, optimized, and disseminated. The available literature suggests we need to do better. For example, according to one report, a substantial percentage (25%–72%) of junctional devices were not placed correctly or did not achieve hemostasis.[44] We are not criticizing these devices nor denigrating their potential. Rather, we believe manual or genicular PEAC offers an important adjunct role, especially while troubleshooting a device and as the patient rushed to definitive rescue.

Conclusion

As with much prehospital resuscitation research, evidence exists for PEAC but it is of low quality and frequently from collateral populations, requiring inference. Accordingly, clinical recommendations such as ours are at the level of expert opinion only. We believe the available indirect evidence supports the use of PEAC when faced with massive lower abdominal or pelvic hemorrhage. The available evidence and opinion support early application of PEAC until either (1) a suitable device (or hemostatic packing) can be applied or (2) an invasive procedure such as REBOA or resuscitative thoracotomy can be performed by a suitably skilled clinician, and as the victim is transported to surgical rescue.

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Disclaimer

The views expressed do not necessarily represent those of our respective employers.

Author Contributions

All authors equally contributed to the drafting and editing of this review, and read and approved the final manuscript.

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References

1. **van Oostendorp SE, Tan ECTH, Geeraedts LMG.** Prehospital control of life-threatening truncal and junctional haemorrhage is the ultimate challenge in optimizing trauma care; a review of treatment options and their applicability in the civilian trauma setting. *Scand J Trauma Resusc Emerg Med*. 2016;24(1):110.
2. **Smith S, White J, Wanis KN, et al.** The effectiveness of junctional tourniquets. *J Trauma Acute Care Surg*. 2018;86(3):532–539.
3. **Eastridge BJ, Mabry RL, Seguin P, et al.** Death on the battlefield (2001–2011). *J Trauma Acute Care Surg*. 2012;73:S431–S437.
4. **Markov NP, DuBose JJ, Scott D, et al.** Anatomic distribution and mortality of arterial injury in the wars in Afghanistan and Iraq with comparison to a civilian benchmark. *J Vasc Surg*. 2012;56(3):728–736.
5. **Smith ER, Shapiro G, Sarani B.** Fatal wounding pattern and causes of potentially preventable death following the pulse night club shooting event. *Prehospital Emerg Care*. 2018;22(6):662–668.
6. **Winstanley M, Smith JE, Wright C.** Catastrophic haemorrhage in military major trauma patients: a retrospective database analysis of haemostatic agents used on the battlefield. *J R Army Med Corps*. 2019;165(6):405–409.
7. **Chen J, Benov A, Nadler R, et al.** Testing of junctional tourniquets by medics of the Israeli Defense Force in control of simulated groin hemorrhage. *J Spec Oper Med*. 2016;16(1):36–42.
8. **Kragh JF, Kotwal RS, Cap AP, et al.** Performance of junctional tourniquets in normal human volunteers. *Prehosp Emerg Care*. 2015;19(3):391–398.
9. **Theodoridis CA, Kafka KE, Perez AM, et al.** Evaluation and testing of junctional tourniquets by Special Operation Forces personnel: a comparison of the Combat Ready Clamp and the Junctional Emergency Treatment Tool. *J Spec Oper Med*. 2016;16(1):44–50.
10. **Sadek S, Lockey DJ, Lendrum RA, et al.** Resuscitative endovascular balloon occlusion of the aorta (REBOA) in the pre-hospital setting: an additional resuscitation option for uncontrolled catastrophic haemorrhage. *Resuscitation*. 2016;107:135–138.
11. **Sokol KK, Black GE, Willey SB, et al.** Preperitoneal balloon tamponade for lethal closed retroperitoneal pelvic hemorrhage in a swine model. *J Trauma Acute Care Surg*. 2016;81(6):1046–1055.
12. **Sims K, Montgomery HR, Dituro P, et al.** Management of EXTERNAL HEMORRHAGE in Tactical Combat Casualty Care: the adjunctive use of XStat™ compressed hemostatic sponges: TCCC Guidelines Change 15-03. *J Spec Oper Med*. 2016;16(1):19–28.
13. **Cantle PM, Hurley MJ, Swartz MD, et al.** Methods for early control of abdominal hemorrhage: an assessment of potential benefit. *J Spec Oper Med*. 2018;18(2):98–104.
14. **Riley D, Burgess R.** External abdominal aortic compression: a study of a resuscitation manoeuvre for postpartum haemorrhage. *Aneasth Intensive Care*. 1994;5(57):1–5.
15. **Douma M, Smith KE, Brindley PG.** Temporization of penetrating abdominal-pelvic trauma with manual external aortic compression: a novel case report. *Ann Emerg Med*. 2014;64(1):79–81.
16. **Douma MJ, Picard C, O'Dochartaigh D, et al.** Proximal external aortic compression for life-threatening abdominal-pelvic and junctional hemorrhage: an ultrasonographic study in adult volunteers. *Prehosp Emerg Care*. 2019:23(4):538–542.
17. **Jacobs LM, Burns KJ, Langer G, et al.** The Hartford Consensus: a national survey of the public regarding bleeding control. *J Am Coll Surg*. 2016;222(5):948–955.
18. **World Health Organizations (WHO).** *WHO Recommendations for the Prevention and Treatment of Postpartum Haemorrhage*. Geneva, Switzerland: World Health Organization; 2012.
19. **The Society of Obstetricians and Gynaecologists of Canada.** *Advances in Labour and Risk Management. ALARM Course Manual*. 22nd ed. The Society of Obstetricians and Gynaecologists of Canada. 2015. https://alarm.cfpc.ca/wp-content/uploads/2015/05/22nd-Ed-Manual-Printable-Version.pdf. Accessed 29 September 2019.
20. **Queensland Government.** Clinical Practice Procedures: Obstetrics/Bimanual Compression. April 2016.
21. **Soltan MH, Sadek RR.** Experience managing postpartum hemorrhage at Minia University Maternity Hospital, Egypt: no mortality using external aortic compression. *J Obstet Gynaecol Res*. 2011;37(11):1557–1563.
22. **Elkhateeb R.** *Adjuvant Effect of Aortic Compression and Carbetocin Injection in Management of Primary Atonic PPH to Improve Outcome*. Vol 1. 2017. http://www.rcog.org.uk. Accessed 16 June 2019.
23. **Soltan MH, Imam HH, Zahran KA, et al.** Assessing changes in flow velocimtery and clinical outcome following use of an

external aortic compression device in women with postpartum hemorrahe. *Int J Gynaecol Obstet*. 2010;110(3):257–261
24. **Treble J.** How to get the post-partum haemorrhage patient in your aircraft and to definitive care—a new option for flight nurses. Conference presentation at the: August 2016.
25. **Treble J.** Post-partum haemorrhage "another option." Oral presentation at the: August 2016.
26. **Kin N, Hayashida M, Chang K, et al.** External manual compression of the abdominal aorta to control hemorrhage from a ruptured aneurysm. *J Anesth*. 2002;16(2):164–166.
27. **Van Roekens CN, Zuckerberg AL.** Emergency management of hypercyanotic crises in tetralogy of Fallot. *Ann Emerg Med*. 1995;25(2):256–258.
28. **Blaivas M, Shiver S, Lyon M, et al.** Control of hemorrhage in critical femoral or inguinal penetrating wounds-an ultrasound evaluation. *Prehosp Disaster Med*. 2006;21(6):379.
29. **Badowski A, Zaraś T.** [Methods of emergency control of hemorrhage]. *Wiad Lek Wars Pol*. 1983;36(3):249–259.
30. "These simple steps could save a stabbing victims' lives." *The Guardian*. 24 May 2006. https://www.theguardian.com/commentisfree/2006/may/24/comment.ukcrime
31. **Paix BR, Tingey DJ, Copley G, et al.** Prehospital external aortic compression for temporizing exsanguinating sub-diaphragmatic hemorrhage—a promising technique, but with challenges: four illustrative cases, including two survivors. *Prehosp Disaster Med*. 2020;35(1):115-118. doi:10.1017/S1049023X19005235
32. **Michel WB, Lachance A, Turcotte A-S, Morris J.** Point-of care ultrasonographically guided proximal external aortic compression in the emergency department. *Ann Emerg Med*. 2019;74(5):706-710. doi:10.1016/j.annemergmed.2019.06.007.
33. **Douma M, Brindley PG.** Abdominal aortic and iliac artery compression following penetrating trauma: a study of feasibility. *Prehosp Disaster Med*. 2014:29(3):299–302.
34. **Douma MJ, O'Dochartaigh D, Brindley PG.** Optimization of indirect pressure in order to temporize life-threatening haemorrhage: a simulation study. *Injury*. 2016;47(9):1903–1907.
35. **Douma MJ, O'Dochartaigh D, Brindley PG.** Bi-manual proximal external aortic compression after major abdominal-pelvic trauma and during ambulance transfer: a simulation study. *Injury*. 2017;48(1):26–31.
36. **Taylor D, Coleman M, Parker P.** The evaluation of an abdominal aortic tourniquet for the control of pelvic and lower limb hemorrhage. *Mil Med*. 2013;178(11):1196–1201.
37. **Brindley PG, Douma M.** Resuscitation following penetrating abdominal and pelvic trauma: novel insights and useful reminders. *Resuscitation*. 2013;84(12):e147-8.
38. **Farr WD.** *The Death of the Golden Hour and the Return of the Future Guerrilla Hospital*. https://jsou.libguides.com/jsoupublications. Accessed 10 January 2019.
39. **Tjardes T, Luecking M.** The Platinum 5 min in TCCC: analysis of junctional and extremity hemorrhage scenarios with a mathematical model. *Mil Med*. 2018;183(5–6):e207–e215.
40. **Rådegran G.** Ultrasound Doppler estimates of femoral artery blood flow during dynamic knee extensor exercise in humans. *J Appl Physiol*. 1997;83(4):1383–1388.
41. **Flecha I, Naylor JF, Schauer SG, et al.** Combat lifesaver-trained, first-responder application of junctional tourniquets: a prospective, randomized, crossover trial. *Mil Med Res*. 2018;5(1):31.
42. **Rall JM, Redman TT, Ross EM, et al.** Comparison of zone 3 resuscitative endovascular balloon occlusion of the aorta and the abdominal aortic and junctional tourniquet in a model of junctional hemorrhage in swine. *J Surg Res*. 2018;226:31–39.
43. **Kronick SL, Kurz MC, Lin S, et al.** Part 4: Systems of care and continuous quality improvement. *Circulation*. 2015;132(18; suppl 2):S397–S413.
44. **Schauer SG, April MD, Fisher AD, et al.** Junctional tourniquet use during combat operations in Afghanistan: the prehospital trauma registry experience. *J Spec Oper Med*. 2018;18(2):71–74.