Combat Trousers as Effective Improvised Pelvic Binders

A Comparative Cadaveric Study

Andrew Loftus, MB BCh, MChem, MPhil[1]; Rhys Morris, MBBS, BSc, MSc, MRCS[2]; Yasmin Friedmann, PhD[3]; Ian Pallister, MBBS, MMed Sci (Trauma), FRCS, MD[4]; Paul Parker, FIMC, FRCSEd (Orth)[5]*

ABSTRACT

Background: Improvised explosive devices and landmines can cause pelvic fractures, which, in turn, can produce catastrophic hemorrhage. This cadaveric study compared the intrapelvic pressure changes that occurred with the application of an improvised pelvic binder adapted from the combat trousers worn by British military personnel with the commercially available trauma pelvic orthotic device (TPOD). **Methods:** Six unembalmed cadavers (three male, three female) were used to simulate an unstable pelvic fracture with complete disruption of the posterior arch (AO/OTA 61-C1) by dividing the pelvic ring anteriorly and posteriorly. A 3–4cm manometric balloon filled with water was placed in the retropubic space and connected to a 50mL syringe and water manometer via a three-way tap. A baseline pressure of 8cmH_2O (average central venous pressure) was set. The combat trouser binder (CTB) and TPOD were applied to each cadaver in a random sequence and the steady intrapelvic pressure changes were recorded. Statistical analysis was performed using the Wilcoxon rank-sum test and a paired *t* test depending on the normality of the data to determine impact on the intrapelvic pressure of each intervention compared with baseline. **Results:** The median steady intrapelvic pressure achieved after application of the CTB was 16cmH_2O and after application of the TPOD binder was 18cmH_2O, both of which were significantly greater than the baseline pressure ($p < .01$ and .036, respectively) but not significantly different from each other ($p > .05$). **Conclusion:** Pelvic injuries are increasingly common in modern theaters of war. The CTB is a novel, rapidly deployable, yet effective, method of pelvic binding adapted from the clothes the casualty is already wearing. This technique may be used in austere environments to tamponade and control intrapelvic hemorrhage.

Keywords: *pelvic fracture; pelvic binder; trauma; hemorrhage; coagulopathy; military; combat; prehospital emergency care*

Introduction

Pelvic fractures are life-threatening injuries that should be suspected in all major trauma patients; their overall incidence is 8%, with high mortality.[1] In recent military conflicts, improvised explosive devices (IEDs) have been widely used to devastating effect. IEDs most often cause lower limb injury and amputation, with blast damage directed upward to the perineum and pelvis. The injury pattern caused by IEDs means pelvic fractures are now more common in military patients. In a recent retrospective analysis of 77 military personnel with traumatic lower limb amputations, 22% had an associated pelvic fracture, of which 50% of this subset had unstable ring fractures.[2,3]

Pelvic fractures have a high associated mortality. The main cause of death is hemorrhage,[4,5] which is venous in origin in 85% of cases.[6] Other sources of bleeding include fractured bone ends and ruptured iliac vessels.[7–9] Prompt reduction and stabilization of pelvic ring injuries are crucial in managing the substantial hemorrhage associated with these injuries.[7,10] Prevention of this hemorrhage fits within the concept of damage control resuscitation to prevent the loss of clotting factors contributing to coagulopathy, hypothermia, and acidosis—the "lethal triad."[13] Early identification and management of a pelvic fracture at the prehospital stage are essential to reduce the mortality resulting from hemorrhage into the intrapelvic space and has recently been included into the hemorrhage component of the Tactical Combat Casualty Care algorithm.

This cadaveric study assessed the changes in intrapelvic pressure after application of a pelvic binder adapted from the combat trousers that British soldiers wear. We have termed this the combat trouser binder (CTB). The intrapelvic pressure changes after application of the trauma pelvic orthotic device (TPOD) were measured and, finally, the two interventions were compared via statistical analysis. The methodology was adapted from previous pilot study performed at Swansea University Medical school and further developed in a study performed at the Royal College of Surgeons, which measured the actual change in intrapelvic pressure[11,12] rather than use surrogate markers such as symphyseal diastasis or pelvic circumference.[7,15,16]

Materials and Methods

Ethical approval was sought from the local ethics governing body, which found the research was within the scope of the

*Correspondence to Andrew.Loftus.RN@gmail.com

[1]**Surg Lt Loftus** is with the Department of Trauma and Orthopaedics, Queen Elizabeth Hospital, Birmingham, UK. [2]**Dr Morris** is a junior trauma fellow, University Hospital of Wales, Heath Park, Cardiff, UK. [3]**Dr Friedmann** is at Cellnovo Limited, Pencoed Technology Centre, UK, and formerly Swansea University, Singleton Park, Swansea, UK. [4]**Prof Pallister** is with the Department of Trauma and Orthopaedics, Morriston Hospital, Swansea, UK. [5]**Col Parker** is with the Department of Trauma and Orthopaedics, Queen Elizabeth Hospital, Birmingham, UK, and is senior lecturer in SOF medicine at University College Cork.

anatomy license held by Swansea University College of Medicine. The Royal College of Surgeons England accepted this confirmation. Six unembalmed cadavers (three male, three female) were examined in the Wolfson Surgical Skills Centre at the Royal College of Surgeons of England in London. None of the cadavers had signs of previous pelvic trauma. An unstable pelvic fracture was created in each cadaver by disrupting the pelvic ring at the pubic symphysis and sacroiliac joint by division of the iliolumbar, sacrospinous, and sacrotuberous ligaments (Figure 1). The specific steps involved in this process are summarized in Table 1 and are demonstrated in Figure 2. The AO/OTA classification system describes this as a 61-C1, meaning an unstable fracture of the pelvis with complete disruption of the posterior arch—in essence, an entirely separated hemi-pelvis. This fracture type (i.e., unstable ring) is the most predominant in IED blast injuries.[2,3]

Figure 1 *Representation demonstrating the positions divided in cadaveric specimens, describing an unstable fracture of the pelvis with complete disruption of the posterior arch (AO/OTA 61-C).*

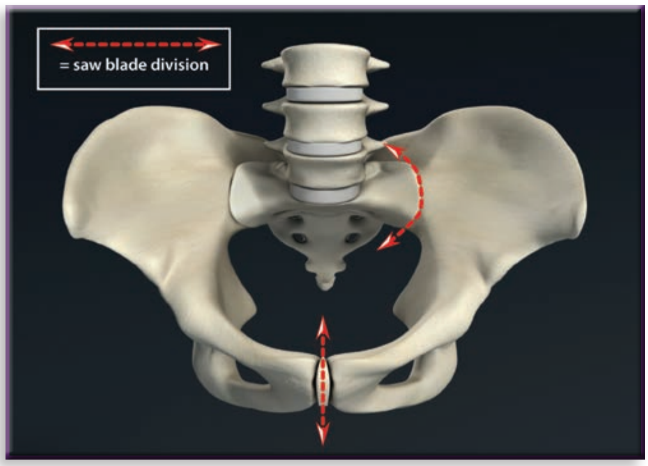


Table 1 *Steps Followed in Creating an Unstable Fracture of the Pelvis With Complete Disruption of the Posterior Arch (AO/OTA 61-C1) for Each Cadaver*

Step	Description
1	The shortest possible midline incision was made to allow dissection down to the pubic symphysis.
2	The pubic symphysis was divided (Figure 2, top left).
3	A Finochietto rib retractor was placed in the divided pubic symphysis and opened to 2cm.
4	The cadaver was then placed prone and a longitudinal incision was made from 5cm proximal to the posterior iliac spine to the level of the ischial tuberosity on one side (Figure 2, bottom left).
5	After dissection down to the ilium, the iliolumbar ligament was divided and a Lebsche knife was used to divide the posterior aspect of the ilium as close to the sacroiliac joint as possible.
6	At the distal end of the posterior wound, the sacrotuberous and sacrospinous ligaments were divided.
7	A Finochietto rib retractor was placed in the divided posterior arch and opened to 2cm (Figure 2, bottom right).
8	The cadaver was returned to a supine position to allow insertion of the manometric apparatus to monitor intrapelvic pressure (Figure 2, top right).

A water-tight balloon was connected to a 50mL syringe and water manometer via a three-way tap. This was placed in the retropubic space and the volume of fluid was then adjusted via the syringe to reset the pressure (Figure 3). A baseline pressure

Figure 2 *From top left, counterclockwise: division of the pubic symphysis; prone cadaver iliac crest to ischial tuberosity marked prior to division; Finochietto rib retractor used to open divided posterior arch to 2cm; and manometric apparatus before introduction to retropubic space.*

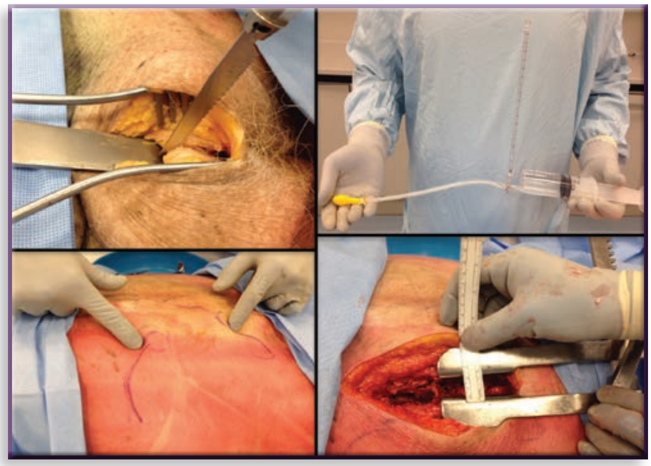


Figure 3 *Application of the trauma pelvic orthotic device to a prepared cadaveric specimen. This also demonstrates the balloon manometric device; the balloon is in the retropubic space.*

of 8cmH_2O was used for each intervention. During reduction maneuvers, care was taken to ensure that the balloon was not disturbed or trapped by the reduced pubic symphysis. In between each intervention, the 2cm diastasis in the pubic symphysis was reestablished using the Finochietto rib spreader, and the knees were positioned 20cm apart to standardize experimental conditions.

Two interventions were considered: application of the TPOD and application of the CTB. Application of the TPOD is demonstrated in Figure 3, which also demonstrates the balloon manometric system in situ. To improvise a pelvic binder, a standard issue pair of British military personal clothing system (PCS) trousers were put onto each specimen. The CTB was created by cutting the anterolateral-lateral aspects of the trouser legs to the level of the greater trochanters. The free fabric (previously covering the legs) was then bound around the pelvis. Combat trousers currently use a tie system built into the inferior aspect of each trouser leg; this is intended to be used to blouse the trouser legs. However, this tie system can be used to secure the binder in its improvised role. Table 2 outlines the specific steps in creating the improvised pelvic binder, Figure 4 illustrates these schematically, and Figure 5 demonstrates this process. An example of the implemented CTB complete is shown in Figure 6 on a live volunteer without any instrumentation.

Table 2 *Steps Followed in Creating a CTB, Using a Standard-Issue PCS Trouser*

Step	Description (relating to Figure 4)
1	Standard-issue PCS trousers were placed onto the cadaver (Figure 4a).
2	Anterolateral aspects of the trouser legs are cut superiorly to the level of the greater trochanters, leaving a free fabric previously covering the legs.
3	The free fabric is laid out laterally from the patient (Figure 4b).
4	The free flaps of fabric are wrapped around the around the pelvis at the level of the greater trochanters and tension is applied circumferentially (Figure 4c).
5	The lower leg ties are used to secure the tensioned fabric in place, securing the binder (Figure 4d).
6	Pressure measurements are then taken with the manometer via the suprapubic incision (Figure 5d).

Figure 4 *Illustration of Steps Followed in Creating a CTB, Using a Standard-Issue PCS Trouser.*

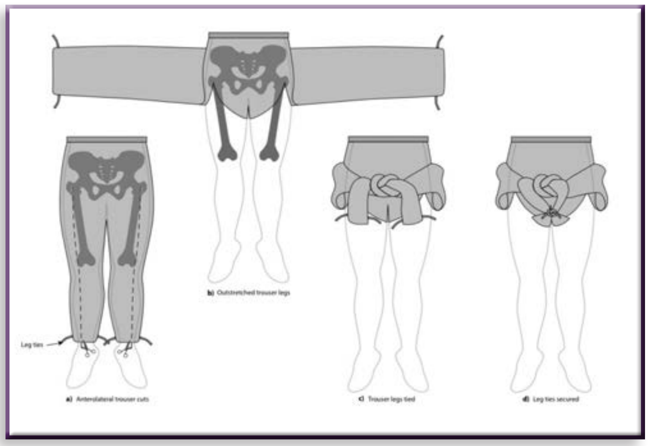


Figure 5 *Counterclockwise from top left:* **(A)** *anterolateral aspects of the PCS trousers legs are cut superiorly to the level of the greater trochanters.* **(B)** *The free fabric is laid out laterally from the specimen.* **(C)** *The free flaps are wrapped around the pelvis, tension is applied circumferentially, and secured with leg ties.* **(D)** *Pressure measurements are then taken with the manometer via the suprapubic incision.*

Figure 6 *Example of the CTB on a live volunteer, without instrumentation.*

After each intervention, it was noted that the pressures obtained would peak and then level off at a steady pressure. It was thought the steady pressures achieved would provide a more accurate measure of the effect of each intervention and, therefore, these pressures were used for the statistical analysis.

Results

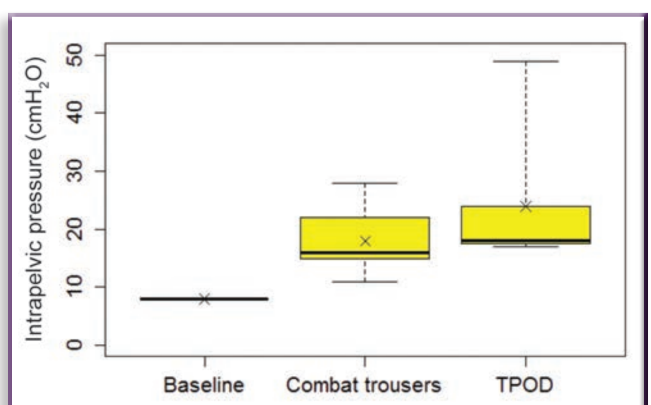
Six cadavers were used for this phase of the study; baseline pressure before any intervention was 8cmH_2O. The Shapiro-Wilk test of normality was applied to both data sets. Combat trousers were normally distributed. TPOD pressure measurements were not normally distributed.

After application of CTB, the median, mean (standard error [SE]) and range of the steady intrapelvic pressures obtained were 16, 18 (SE, 3), and 11–28cmH_2O, respectively. A paired *t* test confirmed that these pressure increases over the baseline were statistically significant ($p < .01$).

After application of the TPOD device, the median, mean (SE), and range of the steady intrapelvic pressures obtained were 18, 24 (SE, 5), and 17–49cmH_2O, respectively. A Wilcoxon rank-sum test confirmed that these pressure increases over the baseline were significant ($p < .036$).

There was no statistically significant difference, using the Wilcoxon rank-sum test, in intrapelvic pressures between the two interventions ($p > .05$). All data are presented in Figure 7.

Figure 7 *Study results showing median values (black horizontal lines), interquartile ranges (yellow), and mean values (×) comparing the effect of the CTB and the TPOD on intrapelvic pressure at equilibrium compared with baseline. The whiskers extend to the maximum and minimum values in the data set.*



The peak initial pressure was recorded for the CTB at 33.5cmH_2O, which dropped to the steady pressure, where it remained. There was no further change in intrapelvic pressure over time once the steady pressures were achieved, as determined by the manometric system. This suggests that the observed steady pressure changes were not transient.

Discussion

The UK national guidelines recommend the prehospital use of pelvic binders in managing patients with major trauma if there is any suspicion of a pelvic fracture given the mechanism of injury, symptoms, or clinical findings.[4,17] The Committee on Tactical Combat Casualty care recently incorporated pelvic-binder application into the hemorrhage component of the MARCH algorithm (i.e., massive hemorrhage, airway, respiratory, circulation, head or spinal or other injury). The application of a pelvic binder likely acts to prevent hemorrhage via several mechanisms in an unstable pelvic fracture. First, the stabilization or splinting of newly fractured bone ends prevents further laceration of soft tissue and vasculature. Second, this reduction in movement promotes stable clot formation.[6] Third, decreasing the intrapelvic volume increases intrapelvic pressure and tamponades venous bleeding. Biomechanical studies have shown pelvic binders to be effective in reducing the symphyseal diastasis[15,16,18] and pelvic width,[6] both of which should theoretically increase intrapelvic pressure by reduction in volume of the intrapelvic space.

Both the commercially available pelvic binder and those improvised using combat trousers significantly increased intrapelvic pressures from the baseline. The latter method is simple, inexpensive, and uses equipment available to all British soldiers in any environment and combat situation. Very similar trousers are used by militaries across the globe. These findings are particularly important clinically because the pressures obtained were considerably greater than normal central venous pressures (8cmH_2O).[14] This suggests these interventions could be of use in tamponading venous bleeding from unstable pelvic fractures, which is essential in the prehospital management of pelvic injury.[4,19]

The cadaveric model used here was adapted from a pilot study[11] that was refined and developed in a larger study that used a balloon manometer to assess the change in intrapelvic pressure before and after an intervention.[12] Results from this study confirmed the methodology in allowing reliable monitoring and measuring of intrapelvic pressure changes after interventions. Change in intrapelvic pressure is likely directly proportional to the mechanism of action of intrapelvic tamponade. The results from this study also echo the results from the previous study where pelvic binder and legs bound over a bolster increased intrapelvic pressure significantly compared with the baseline pressure and that the pressure achieved using both binding methods was not statistically different from the pressure achieved with the TPOD binder.[12]

Our study differs from those previously published in that we used the intrapelvic pressure as the end point. Several other studies have quantified the reduction in the symphyseal diastasis.[15,20,21] The Nunn et al. cadaveric study[21] also measured intraperitoneal pressure changes after application of circumferential pelvic pressure. Their study demonstrated compression at the greater trochanter produced the smallest intraperitoneal pressure change,[21] which suggests that intraperitoneal pressure is of little use in measuring binder effect when binders are placed correctly at the greater trochanter. We believe quantifying the actual intrapelvic pressure change bore a closer relation to tamponade as the mechanism of action and we encourage use of this metric.

With respect to the preparation of each cadaveric model, in generating the simulated pelvic injuries described as AO/OTA 61-C1, we used a surgical approach to ensure standardization between specimens. A previous study used an external rotation force to both iliac wings to create an open-book pelvic fracture.[22] It is possible that this approach would create different injury patterns in different cadavers when categorized by the AO/OTA systematic approach and, therefore, may impact the ability to compare results between specimens in a model and between studies.

Removing the trouser legs from a patient should not significantly risk hypothermia. Appropriate prehospital management of a trauma patient includes the mitigation of hypothermia using products such as the hypothermia management and prevention kit, blankets or other appropriate items. Simple PCS should not be the only item standing between a trauma patient and hypothermia.

Despite the benefits of pelvic binder application in the prehospital setting,[15,20,21] there are important considerations to their use in combat settings. For example, military forces are increasingly operating in small groups in austere, remote, and hostile environments. Therefore, they are limited in the volume and weight of equipment that can reasonably be taken into such environments. Although, ideally, all groups would have access to a pelvic binder, this is not always practicable given the dimensions of current devices and the volume of equipment required for operational effectiveness.

Another unique challenge in this context is time from point of wounding to extrication. An increasingly common problem is the requirement of prolonged field care. This can mean a patient being held in an austere environment due to remote location or combat activity far longer than ideal medical management would dictate. Pelvic stabilization in this context is vital to reduce hemorrhage; however, the specific equipment to do so may not always be available.

Military frontline units are becoming ever more flexible to adapt to these operational requirements. It is not always possible to have specific equipment, due to logistical restrictions. Flexible and adaptable items are essential to meet this challenge. With this theme, we propose that British military PCS trousers can be adapted rapidly and used as an improvised pelvic binder, thus providing a possible method of stabilizing pelvic fractures in the absence of specialized equipment. Every member of the British Armed Forces in an operational theatre wears this item and militaries worldwide use very similar versions.

Limitations of our study include the small sample size of six cadavers. Despite this, our study has demonstrated clear trends in both interventions significantly increasing intrapelvic pressure. A further possible confounder of the study is that it was conducted in a very controlled, standardized environment. Two senior pelvic surgeons ensured appropriate placement and use of each intervention. This has the advantage of reducing bias or errors due to suboptimal binder use. In clinical practice, up to 39% of pelvic binders are placed inaccurately, with reduced efficacy in closing of the symphyseal diastasis.[5] It is unclear, however, what effects malpositioning of binders would have had on our results, and this consideration is particularly pertinent for the improvised binders. They would potentially be used in combat situations at the point of wounding well away from the expertise of a pelvic surgeon. In these circumstances, suboptimal binder application may be more likely because of the stress of the environment in which many lower limb and pelvic injuries occur in an operational theater.[23]

Conclusion

Overall, this study shows that both the TPOD and the CTB are effective in significantly increasing intrapelvic pressures to a clinically relevant level. There was no significant superiority of the TPOD over the CTB. Combat soldiers are exclusively deployed wearing PCS trousers that can be adapted rapidly into a potentially lifesaving pelvic binder without the need for specialist devices. The described technique could be used in the early management of life-threatening pelvic injuries in operational theaters where dedicated resources are limited.

Funding
This work was supported by Prof Vishy Mahadevan, MBBS, PhD, FRCS, the Royal College of Surgeons, and Stephen D. Atherton, medical illustrator, MA, RMIP, MIMI, Morriston Hospital, Swansea, UK SA6 6NL.

Disclosures
The authors have nothing to disclose.

References
1. **Giannoudis PV, Grotz MRW**. There have been changes in the incidence and epidemiology of pelvic ring fractures in recent decades? *J Trauma*. 2007;63:875–883.
2. **Mossadegh S, Midwinter M, Parker P.** Developing a cumulative anatomic scoring system for military perineal and pelvic blast injuries. *J R Army Med Corps*. 2013;149(suppl 1):i40–44.
3. **Cross AM, Davis C, Penn-Barwell J, et al.** The incidence of pelvic fractures with traumatic lower limb amputation in modern warfare due to improvised explosive devices. *J R Nav Med Serv.* 2014;100 (2):152–156.
4. **Scott I, Porter K, Laird C, et al.** The prehospital management of pelvic fractures: initial consensus statement. *Emerg Med J*. 2013; 30(12):1070–1072.
5. **Bonner TJ, Eardley WGP, Newell N, et al.** Accurate placement of a pelvic binder improves reduction of unstable fractures of the pelvic ring. *J Bone Joint Surg (Br)*. 2011;93B:1524–1528.
6. **Montmany S, Rebasa P, Luna A, et al.** Source of bleeding in trauma patients with pelvic fracture and haemodynamic instability. *Cir Esp*. 2015;93(7):450–454.
7. **Krieg JC, Mohr M, Ellis TJ, et al.** Emergent stabilization of pelvic ring injuries by a controlled circumferential compression: a clinical trial. *J Trauma*. 2005;59:659–664.
8. **Papakostidis C, Giannoudis PV.** Pelvic ring injuries with haemodynamic instability: efficacy of pelvic packing, a systematic review. *Injury.* 2009;40S4:S53–S61.
9. **Pascarella R, Del Torto M, Politano R, et al.** Critical review of pelvic fractures associated with external iliac artery lesion: a series of six cases. *Injury.* 2014;45(2):374–378.
10. **Croce MA, Magnotti LJ, et al.** Emergent pelvic fixation in patients with exsanguinating pelvic fractures. *J Am Coll Surg*. 2007; 204:935–942.
11. **Morris R, Loftus A, Lygas A, et al.** Pelvic pressure changes after a fracture: a pilot cadaveric study assessing the effect of pelvic binders and limb bandaging. *Injury.* 2016;47(2):295.
12. **Morris R, Loftus A, Friedmann Y, et al.** Intra-pelvic pressure changes after pelvic fracture: a cadaveric study quantifying the effect of a pelvic binder and limb bandaging over a bolster. *Injury.* 2017;8(4):833–840.
13. **Chesser TJS, Cross AM, Ward AJ.** The use of pelvic binders in the emergent management of potential pelvic trauma. *Injury.* 2012; 43:667–669.
14. **Yentis SM, Hirsch NP, Ip JK.** *Anaesthesia and intensive care. An encyclopaedia of principles and practice*. 5th ed. Edinburgh, UK: Churchill-Livingstone Elsevier.
15. **DeAngelis NA, Wixted JJ, Drew J, et al.** Use of the trauma pelvic orthotic device (TPOD) for provisional stabilisation of anterior-posterior compression type pelvic fractures: a cadaveric study. *Injury.* 2008;39:903–936.
16. **Tan ECTH, Van Stigt SFL, Van Vugt AB.** Effect of a new pelvic stabilizer (TPOD®) on reduction of pelvic volume and haemodynamic stability in unstable pelvic fractures. *Injury.* 2010;41: 1017–1021.
17. **National Institute for Health and Clinical Excellence.** Trauma overview. February 2016. http://pathways.nice.org.uk/pathways/trauma. Accessed 10 June 2017.
18. **Bottlang M, Simpson T, Sigg J, et al.** Non-invasive reduction of open-book pelvic fractures by circumferential compression. *J Orthop Trauma*. 2002;16(6):367–373.
19. **Spanjersberg WR, Knops SP, Schep NWL, et al.** Effectiveness and complications of pelvic circumferential compression devices in patients with unstable pelvic fractures: a systematic review of literature. *Injury.* 2009;40:1031–1035.
20. **Bottlang M, Krieg JC, Mohr M, et al.** Emergent management of pelvic ring fractures with use of circumferential compression. *J Bone Joint Surg (Br)*. 2002;84A(suppl 2):43–47.
21. **Nunn T, Cosker TDA, Bose D, et al.** Immediate application of improvised binder as a first step in extended resuscitation from life-threatening hypovolaemic shock in conscious patients with unstable pelvic injuries. *Injury.* 2007;38:125–128.
22. **Grimm MR, Vrahas MS, Thomas KA.** Pressure-volume characteristics of the intact and disrupted pelvic retroperitoneum. *J Trauma*. 1998;44(3):454–459.
23. **Mamczak CN, Elster EA.** Complex dismounted IED blast injuries: the initial management of bilateral lower limb extremity amputations with and without pelvic and perineal involvement. *J Surg Orthop Adv.* 2012;21(1):8–14.

The Special Operations Medical Association's Official Journal

JSOM

JOURNAL *of* SPECIAL OPERATIONS MEDICINE™

UNCONVENTIONAL WARFARE
UNCONVENTIONAL MEDICINE

Fall 2017
Volume 17, Edition 3

THE JOURNAL FOR OPERATIONAL MEDICINE AND TACTICAL CASUALTY CARE

Inside this Issue:

- Case Report of Exertional Heat Illness › Airway Kits in Combat: A Case Series
- Case Report: Aspirin for Suspected Acute Ischemic Stroke
- Unwrapping a Tourniquet › Combat Trousers as Improvised Pelvic Binders
- Surgical Instruments for Expeditionary Surgical Teams › GHOST Operational Concept
- Bite Risk When Working With Military Dogs › Prehospital TXA Administration
- New and Standard BVM Ventilation-Rate Comparison
- Junctional Hemorrhage Model Testing XSTAT®
- Fatalities Among Police Officers During Tactical Incidents
- Optimizing Simulation and Moulage in Training
- Atropine Eye Drops › Prehospital Chest Seal Placement in Afghanistan
- No Ordinary Sleeper Cell › Humanitarian Struggle in Burma's Conflict Zones
- Ongoing Series: Human Performance Optimization, Infectious Diseases, Injury Prevention, Law Enforcement & Tactical Medicine, Preventive Medicine, Prolonged Field Care, SOFsono Ultrasound Series, Special Talk: An Interview, The World of Special Operations Medicine, Book Reviews, TCCC Updates, Dedication, *and more!*

Dedicated to the Indomitable Spirit and Sacrifices of the SOF Medic

A Peer-Reviewed Journal That Brings Together the Global Interests of Special Operations' First Responders