Review

Paramedic POCUS, Turning Our Heads to the Prehospital Side of the Fence: A Narrative Review of Education, Training and Future Direction

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Background

Portable ultrasound is a burgeoning technology with unrealized potential at a critical point in its evolution [1]. Francis Galton first generated ultrasound waves in 1876; however, it wasn't until 1940 that ultrasound was first applied to clinical medicine [2]. Reaching a "tipping point", ultrasound is being rapidly assimilated into many medical specialties beyond radiology, now in the hands of non-radiologist, non-cardiologist novel users [2]. Diagnostic medical ultrasound has been widely incorporated into emergency departments since the early 1980's; however, machine size and cost has limited its use to the hospital setting [3]. The democratization of ultrasound to paramedicine could alter clinical decision-making, improve time to perioperative care, and enhance triage capabilities [1-3]. An augmented ultrasound physical examination would allow for treasurable clinical findings otherwise unobtainable to paramedics, revolutionizing prehospital medicine in a manner that is unprecedented by other tools in the arsenal of emergent care.

Demands on the healthcare system are rapidly increasing due to population age and growth, igniting an increased reliance on paramedics to carry out assessments and treatments traditionally performed by physicians [4]. Unlike the controlled environment of the emergency department or operating room, a paramedic work ecosystem can be described as austere, subject to immense variability in setting, lighting, and noise [5]. Workspaces range broadly from an ambulance or helicopter to an elevator, staircase, curbside, grocery store aisle, or living room floor [5]. Prehospital providers formulate diagnoses based on impartial information with no access to medical records [5]. Auscultation is one of the few assessments available to paramedics; however, it is difficult to perform in the back of a moving ambulance or on a crowded street [5]. The diagnostic potency of ultrasound, its portability, and ease of use are well-suited features for translation to the unpredictable arena of prehospital medicine [6]. Despite these benefits, ultrasound use in paramedic services across North America has been estimated to be as little as 4.1% [7].

If portable ultrasound was originally intended as an advent of military triage in resource limited settings, why has it failed to become an integral part of paramedic practice [1, 6]? The first emergency ultrasound curriculum was introduced by Mateer et al. in 1994, and has since entered the core curriculum required for residency in emergency medicine [2]. Paramedicine has not yet seen the same integration of ultrasound into teaching curriculums, despite the fact that hand held ultrasound (HHU), as previously mentioned, was arguably designed for out-of-hospital use [1, 6]. The primary objective of this narrative review is to provide insight into the paramedic scope of practice and structure of paramedic services in Ontario. The second objective is to review the literature describing paramedic education in goal directed ultrasound in the following three clinical contexts: focused assessment sonography in trauma (FAST), pneumothorax, and cardiac standstill.

Structure of Paramedic Services

The origin of paramedicine is highly unique. Evolving out of the mortician industry, spanning a 40-year lifespan, prehospital medicine has undergone enormous transformation in both structure and practice [8]. Currently, in Ontario, paramedics work for one or more of 51 municipally run paramedic services regulated under the Ambulance Act (1990) [8]. Ontario has 8 Base Hospital Programs (BHP) which operate as extensions of the Ministry of Health and Long Term Care (MOHLTC) [8].

Seven base hospital programs provide medical direction to land ambulance services, while one base hospital oversees air ambulance utilization [8]. With the exclusion of Saskatchewan, New Brunswick, Alberta, and Nova Scotia, paramedics across Canada are not self-regulated health care professionals [8]. Therefore, all paramedics in Ontario operate under the medical license of their respective base hospital physicians [8]. In Canada, paramedics treat and/or transport approximately 2 million patients annually, while in the United States patient contacts are between 25 and 30 million [5].

Paramedic Scope of Practice

In Canada, paramedic skill sets are variable by service, region, and province. Training or accreditation is partitioned into three levels of care in Ontario: primary care paramedic (PCP), advanced care paramedic (ACP), and critical care paramedic (CCP) [9, 10]. There is an emerging fourth tier of non-emergent care in the community setting, still in a state of development in Canada, commonly referred to as extended care paramedics (ECP) or community paramedics (CP) [4, 9].

The PCP level requires a two-year community college program and successful completion of a provincial examination, the Advanced Emergency Medical Care Assistant (A-EMCA) [9]. PCPs can administer 10 symptom relief medications, including epinephrine, diphenhydramine, dimenhydrinate, salbutamol, acetylsalicylic acid, acetaminophen, ibuprofen, ketorolac, nitroglycerin, and naloxone through oral, intra-nasal, nebulized, intramuscular, and intravenous routes [9]. PCPs perform 12-lead electrocardiographic interpretations and initiate hospital bypass protocols for acute STEMI (ST elevation myocardial infarction), ischemic stroke, burns, and trauma [9]. PCPs also provide basic life support care through oxygen therapy, ETCO2 monitoring, cardiopulmonary resuscitation, manual defibrillation, and are trained in bag-valve-mask ventilation and insertion of supra-glottic airways [9].

Advanced care paramedics (ACP) undergo an additional year of didactic, in-hospital, and in-field training [9]. ACPs can administer medications through all routes described above, as well as intraosseous, endotracheal, and external jugular sites [9]. ACPs perform orotracheal and nasotracheal intubation, needle thoracotomy, synchronized cardioversion, and external transcutaneous cardiac pacing [4, 9]. Advanced care paramedics administer narcotics, antiarrhythmic agents, and inotropes [4, 9].

While PCPs and ACPs work predominately in land ambulance services, critical care paramedics (CCP) have an additional two years of didactic, clinical, and preceptorship training to work in fixed and rotary wing aircrafts [9, 10]. Functioning as a mobile intensive care unit, CCPs have a very extensive pharmacological scope; they also administer blood and blood products [9]. CCPs perform tasks such as interpreting CT-scans of the head and chest X-rays, monitoring intra-aortic balloon pumps, pulmonary artery, central venous, and arterial lines, as well as performing lab value and blood gas analyses [9].

Community paramedics (CP) are often ACPs with new competencies facilitating assessment and treatment of minor injuries and chronic illness surveillance, though the role and aims of CPs are tailored to the needs of each individual community [4]. CPs commonly treat patients at home and in long-term care facilities. They also provide referrals to more appropriate resources within the community in attempt to offset emergency department congestion and EMS call volume [4, 11, 12]. Evolving well beyond stabilization and transport, paramedics are an integral link in the chain of care, providing on-the-spot diagnosis and intervention for a wide range of clinical conditions and maladies [4, 5, 9].

POCUS in Paramedic Services

Understanding paramedic use of ultrasound is challenging, since the majority of paramedic POCUS literature is limited to physician run aeromedical emergency services comprising diverse teams of physicians, flight nurses, and sonographers [3, 13]. Pre-hospital ultrasound is more commonly found in Europe, described in literature of physician-run emergency services in Germany, France and Italy [3, 14]. European prehospital medical providers spend more prolonged periods of time managing and treating patients when compared to their North American counterparts [3]. In North America, paramedic services place a heavy focus on rapid transport times and limiting on scene time, which may explain the slower adoption of ultrasound into prehospital algorithms of care [3]. Throughout Canada, there are currently no published studies on the use of ultrasound in land ambulance services.

Focused Assessment Sonography in Trauma (FAST)

Abdominal and pelvic injuries are a major cause of early death after severe trauma [13]. The FAST exam is a goal directed sonographic assessment of intraperitoneal and pericardial spaces for free fluid whereas the EFAST exam also includes evaluation of pleural spaces [13]. Numerous studies have evaluated the training requirements of physician performed FAST ultrasound assessments; however, far fewer studies have given considerable attention to curricula for teaching paramedics FAST and EFAST exams [1, 6, 13, 15, 16, 17 -29]. It is reasonable to hypothesize that paramedics with less training may require more extensive educational programs than physicians to perform ultrasound assessments such as the FAST exam.

Educational programs for FAST exams tailored to paramedics have ranged widely from four hours over one day to 13 hours over two months of training, with most curricula using a one-day or weekend course [25]. Heegard et al. enrolled 116 paramedics to learn FAST and abdominal aortic ultrasound assessments [17, 25]. The course consisted of a six-hour didactic and practical component with two one-hour refresher courses at three and eight months following the initiation of the course [17, 25]. Over the course of the study, 104 patients were scanned during ground transport and 84 received a full paramedic performed FAST exam [17, 25]. The mean duration to perform the exam was 156 seconds, paramedics were unable to acquire images in as few as 7.7% of patients, and with 100% agreement between paramedic and physician scans [17, 25].

Walcher et al. utilized five anesthetists and four paramedics in a one-day didactic and hands on course using healthy human volunteers and patients with peritoneal dialysis or ascites [25, 26]. Throughout the study, 39 FAST exams were performed in the field and the mean duration of the exam was 174 seconds with both a sensitivity (Sn) and specificity (Sp) of 100% [25, 26]. Computed Tomography (CT) served as the gold standard used to compare paramedic ultrasound findings [25, 26].

Kim et al. trained six level 1 emergency medical technicians (EMT's) on FAST in a two-hour didactic and two-hour practical training program performed on EMT volunteers [25, 27]. A convenience sample of 240 patients receiving abdominal CT within 24 hours of FAST exams was utilized and the abdominal CT served as an evaluative benchmark [25, 27]. The duration of the FAST exam performed by EMTs was 124.9 seconds, Sn was 61.3% and Sp was 96.3% for the detection of peritoneal cavity fluid, while positive predictive value was 89.1% and negative predicative value was 83.2% [25, 27].

Press et al. trained 33 paramedics and nurses to perform extended FAST exams (FAST and pleural assessments) on consenting in-flight trauma patients. Training consisted of three hours didactic and eight hours practical over a 2-month period [13, 25]. In addition, the course utilized pocket flashcards, six Internet based modules, an experiential scan on the helicopter, a one-hour review session, written tests, and an objective structure clinical examination (OSCE) [13, 25]. Course design was unique in its longitudinal scope and multi-faceted approach blending both traditional and Internet based training [13, 25]. Out of 33 paramedics, 27 passed OSCE on first assessment and the remaining six passed after a four-hour remedial session [13, 25].

Unluer et al. conducted a study using four senior paramedics, involving a four-hour didactic and four-hour practical training program for FAST to detect free fluid in the peritoneum of 127 patients admitted to the emergency department following trauma [25, 29]. The exam was performed in less than four minutes, with a Sn of 84.62% and Sp of 97.37%, compared to the gold standard of ultrasound and computerized abdominal tomography (CAT) scan interpretation by radiologists [25, 29].

The sensitivities of paramedic performed FAST exams ranged from 61.3% to 100%, and specificities ranged from 96.3% to 100% [25]. The duration of FAST examination was variable, with a mean time between 124.9 seconds to less than four minutes [25]. These studies demonstrate that with a combination of didactic and practical education, FAST can be effectively taught to paramedics in as little as a one-day course to reach a specificity greater than 96% [25]. A study involving physicians evaluating peritoneal free fluid without identifying parenchymal organ pathology yielded similar results in a one day course, achieving a specificity of 99% [28]. Paramedics perform the FAST exam with comparable accuracy to that of the results from condensed training curricula for physicians, disproving the notion that paramedics require more extensive training to acquire the same skills.

Studies investigating differences in acquisition and retention of FAST skills between paramedics and physicians may be of value to inform and shape clinical practice guidelines. To date, there are only scant studies available which compare the performance of FAST exams by paramedics across different levels of care, regions, or countries. It is currently not known if the results of these studies are generalizable to other settings.

Pneumothorax

Prehospital detection of a pneumothorax is currently limited to auscultation and pertinent physical examination findings such as paradoxical chest rise and fall [30]. The sensitivity of auscultating breath sounds to diagnose a pneumothorax is cited to be as low as 58% in the hospital setting and is imaginably even lower in the prehospital setting [30]. If correctly identified, tension pneumothorax is a life-threatening condition treatable prior to arrival at the emergency department by means of needle decompression [30]. Pleural ultrasound, for the detection of a pneumothorax, has been taught to paramedics in a shorter time than the FAST exam, in as little as 10 minutes, achieving a Sn of 82% and Sp of 94% [25].

A systematic review by McCallum et al. described six studies of paramedic pleural ultrasound training [25]. Between four and 33 paramedics participated in the studies, possessing varying levels of training from EMT to advanced and critical care paramedics [25]. The majority of the studies utilized the absence of sonographic lung sliding (SLS) as the sole marker of pneumothorax [13, 25, 30, 32-35]. The highest Sn (97%) was achieved in a study by Lyon et al, which utilized a 25-minute didactic and practical training model on a cadaver [25, 32]. Conversely, the study yielding the least favorable results was a 75-minute curriculum by Roline et al, wherein only 54% of lung ultrasound images were deemed adequate for interpretation [25, 33].

Preliminary studies have suggested image acquisition and interpretation are independent skills, meaning acquiring an image of diagnostic quality does not necessarily mean the paramedic can adequately interpret the image [25]. More in-depth studies combining acquisition and interpretation have used training curricula that ranged between 25 minutes and 10 hours [25]. The most comprehensive paramedic training program for lung sliding incorporated three markers of pneumothorax: SLS, comet tail artifact and stratosphere signs [25, 34]. This study had the lowest Sn (81%) and Sp (85%); however, paramedics still achieved a sensitivity and specificity comparable with sonographer over-reads [25, 34]. One study conducted a follow up assessment nine months post training, demonstrating skill maintenance of 100% sensitivity and specificity [25, 32]. Two studies described successful application of pleural ultrasound in the field, although no outcome data on patient care is available [32, 35].

The aforementioned studies suggest pleural ultrasound, for the detection of pneumothorax, can be effectively taught to paramedics of varying levels with minimal time investment [25, 30, 32-35]. Discussed elsewhere, pleural ultrasound may have additional application in the field, such as hemothorax, pleural effusion, pneumonia, as well as assisting in the diagnosis of various acute on chronic pulmonary conditions [31, 36].

Ultrasound in Cardiac Standstill

Despite various reviews showcasing cardiac ultrasound to differentiate various etiologies of shock, very few discuss the ability for paramedics to assess only cardiac standstill [25]. Patients in a pulseless electrical activity (PEA) account for up to 30% of out-of-hospital cardiac arrest victims [37]. Both the European and American ACLS guidelines stress the significance of identifying and treating reversible causes of PEA [37-40]. In the prehospital setting, paramedics do not have the capacity to visualize cardiac kinesis, which would, for example, allow the differentiation between true PEA (TPEA) and pseudo PEA (PPEA) [3]. Patients without cardiac standstill have a significantly higher likelihood of survival than patients with cardiac standstill [37]. Equipping paramedics with a mechanical lens to view cardiac activity could improve survival rate in the TPEA and PPEA cardiac arrest subset by informing decisions to continue or cease infield resuscitation efforts [3, 25].

For paramedics to identify cardiac standstill they must be proficient in both cardiac ultrasound image acquisition and interpretation. A prospective educational interventional pilot study by Chin et al. demonstrated 20 paramedics in Houston, Texas had difficulty acquiring cardiac ultrasound images in a one-hour didactic and one -hour hands-on practical training session [30]. Images were scored on a six-point scale, the Cardiac Ultrasound Structural Assessment Scale (CUSAS), developed by Backlund et al. [30, 41]. All paramedics achieved a CUSAS score of three, which required partial ventricular visualization [30]. However, an ‘’adequate image” required a CUSAS score of six and only 11 out of 20 paramedics (55%) were able to obtain passing scores [30]. Views of the heart were acquired in less than 10 seconds for 16 paramedics, one paramedic took approximately 90 seconds, and others ranged between 10-25 seconds [30]. Throughout the study, no observations were made on difficulty of particular cardiac windows over others or long term retention [30].

Chin et al. demonstrated that paramedics had less difficulty interpreting cardiac standstill on prerecorded ultrasound images than acquiring sonographic cardiac views [30]. There was no association between image acquisition and recognition given just over half of the paramedics achieved passing CUSAS scores, yet the average scores for image recognition was high, 9.1 out of 10 [30]. This study also evaluated lung ultrasound for the detection of a pneumothorax, recording the time it took paramedics to obtain clear views of the pleural line [30]. When comparing lung and cardiac acquisition skills, paramedics obtained views of the pleural lines more quickly than cardiac views, (<5 sec vs. 10-25 sec), which suggests cardiac scanning might be more nuanced than pleural ultrasound [30].

Rooney et al. performed a small prospective educational study on cardiac standstill detection with four paramedics after a three-hour training session [42]. Training consisted of two hours of didactic training and one hour hands-on training of the subxiphoid, apical four chamber and left parasternal long axis view on human subjects [42]. For a scan to be judged as adequate, a minimum score of four on a six-point structural assessment scale was required [42]. Nineteen patients were enrolled in the study, but two exams were excluded as they were deemed inadequate for interpretation [43]. Paramedics were able to accurately record 17 cases of cardiac activity and two cases of cardiac standstill [42]. The study results showed 89% of paramedics were successful in obtaining cardiac POCUS images and 100% were able to differentiate between cardiac activity from cardiac standstill [42].

To date, there is no standardized training delineating optimal length and modality of curricula for novel users of cardiac POCUS to achieve and maintain a high level of competency [42, 43]. Emphasis on a number of proctored scans to acquire competency can deter from the need to innovatively blend traditional and non-traditional components of effective training curriculums [13]. A state of the art review of educational curricula of cardiac POCUS in undergraduate medical training cited similar challenges to those described with paramedic education of cardiac ultrasound [43]. In both cohorts of paramedics and undergraduate medical students, scanning the heart accordingly was a more readily absorbable skill than interpreting cardiac ultrasound images [30, 42, 43].

Future Direction

The point of care does not begin in the emergency department, but rather prior to arrival at the hospital in the prehospital setting. In-hospital and prehospital medicine are two sides of the same coin; though head and tail can be discussed separately, they cannot be separated but viewed instead as a dual continuum in a patient's journey [44]. Prehospital ultrasound not only augments the physical examination but also provides a chronological map of patient condition to inform in-hospital management and serves as a potential reference point in the event of patient deterioration [15]. As the Canadian Patient Safety Institute asserts, patients 'depend on many people doing the right thing at the right time' and they depend on a 'system of care', which requires continuous collaboration between healthcare providers [45].

Technological innovation commonly outpaces evidence and there are numerous barriers that can impede the process of acquiring that evidence. Although training curricula on paramedic ultrasound remains heterogeneous, and robust outcome data is yet to be generated, existing literature discussed herein supports ultrasound use by paramedics. Despite numerous applications of paramedic POCUS, usage of ultrasound in the prehospital setting remains surprisingly low [7]. A cross-sectional survey of emergency medical services directors across North America indicate the most significant barrier was cost of equipment and training (89.4% of 255 respondents) [7]. Cost benefit analyses on ultrasound usage would be a valuable contribution to inform paramedic services on decisions surrounding implementation [7, 46]. Other prevalent barriers to implementation include high variability in the level of training of paramedic users and restrictions of time a paramedic can spend with a patient [7, 46]. Constraints of time are a defining feature that distinguishes the Anglo-American from Franco-German models of emergency medical services [46, 47]. As previously stated, paramedic services in North America follow the Anglo-American model, which aims to keep on scene, transport and transfer of care times to a minimum [46, 47]. The type of emergency medical model in place is an important factor to consider when discussing potential alterations to prehospital interventions and practices [46]. It is possible that the starting point for successfully implementing POCUS in paramedicine in Canada may be in the community setting. Being a predominantly non-transported patient demographic, reflecting an evolution towards the Franco-German model of emergency prehospital care, paramedics can spend more time performing additional assessments with their patients [46, 47].

Although it is not yet a standard of care, paramedics across all levels of training have demonstrated proficiency in acquiring POCUS skills with brief training periods in both traumatic and non-traumatic patient populations. Challenges in skill acquisition and retention are not insurmountable. Systematic approaches to non-physician training are in order to ensure quality assurance is given sufficiently high priority [15]. A plethora of ultrasound exams not described in this review also possess potential for implementation in the prehospital setting. Some of these exams include rapid ultrasound for shock and hypotension (RUSH), ultrasound for shock, trauma and resuscitation (USTAR), and POCUS for fracture identification [48]. The FAST exam often dominates discussions on prehospital ultrasound use; however, the highest yield of paramedic POCUS may lay in under-examined, non-traumatic patient populations [49]. More rigorous academic investigation produced by multi-disciplinary teams of experts and novel users is required to determine if paramedic POCUS can ultimately effect clinical decision making and improve patient outcome.

References:

1. Kimura BJ, Amundson SA, Shaw DJ. Hospitalist use of hand-carried ultrasound: preparing for battle. Journal of Hospital Medicine. 2010;5 (3):163-167.

2. Jain A, Stead L, Decker W. Ultrasound in emergency medicine: a colourful future in black and white. International Journal of Emergency Medicine. 2008;1(4):251-252.

3. Nelson B, Chason K. Use of ultrasound by emergency medical services: a review. International Journal of Emergency Medicine. 2008;1 (4): 253-259.

4. Bigham B, Kennedy S, Drennan I, et al. Expanding paramedic scope of practice in the community: a systematic review of the literature. Prehospital Emergency Care. 2013;17(3):361-372.

5. Corman, M. Titrating the rig: how paramedics work in and on their ambulance. Qualitative Health Research. 2018;28(1):47-59.

6. Hoyer H, Vogl S, Schiemann U, et al. Prehospital ultrasound in emergency medicine: incidence, feasibility, indications and diagnoses. European Journal of Emergency Medicine. 2010;17(5):254-259.

7. Taylor J, McLaughlin K, McRae A, et al. Use of prehospital ultrasound in North America: a survey of emergency medical services medical directors. BMC Emergency Medicine. 2014;14(6):1-5.

8. Ontario Paramedic Association. Frequently asked questions. Ontario Paramedic Association Website. https://www.ontarioparamedic.ca/self-regulation/faqs-by-paramedics/. Accessed June 8, 2018.

9. Toronto Paramedic Association. Scope of practice. Toronto Paramedic Association Website. https://www.torontoparamedic.com/scope-of-practice/. Accessed June 8, 2018.

10. Ornge. Programs and Services. Ornge Website. http://ornge.78beta.com/about-us/programs. Accessed June 9, 2018.

11. Verma A, Klich J, Thurston A, et al. Paramedic-initiated home care referrals and use of home care and emergency medical services. Prehospital Emergency Care. 2018;22(3):379-384.

12. Pennycook A, Makower R, Morrison W. The use of emergency ambulance service to an inner city accident and emergency department- a comparison of general practitioner and '999' calls. Journal of the Royal Society of Medicine. 1991;84(12):726-727.

13. Press G, Miller S, Hassan I, et al. Evaluation of a training curriculum for prehospital trauma ultrasound. Journal of Emergency Medicine. 2013;45(6):856-864.

14. Liao S-F, Chen P-J, Chaou C-H, et al. Top-cited publications on point of care ultrasound: the evolution of research trends. American Journal of Emergency Medicine. 2018;36(8):1429-1438.

15. Brooke M, Walton J, Scutt D. Paramedic application of ultrasound in the management of patients in the prehospital setting: a review of the literature. Emergency Medicine Journal. 2010;27:703-707.

16. Heegaard W, Hildebrandt D, Spear D, et al. Prehospital ultrasound by paramedics: results of a field trial. Academic Emergency Medicine. 2010;17(6):624-628.

17. Lapostolle F, Petrovic T, Lenoir G, et al. Usefulness of hand-held ultrasound devices in out-of-hospital diagnosis performed by emergency physicians. American Journal of Emergency Medicine. 2006;24(2):237-242.

18. Lichenstein D, Courret JP. Feasibility of ultrasound in the helicopter. Intensive Care Medicine. 1998;24(10):1119.

19. Jang T, Aubin C, Nuanheim R. Minimum training for right upper quadrant ultrasonography. American Journal of Emergency Medicine. 2004;22(6):439-433.

20. Mandavia D, Bistrain J, Chan L, et al. Focused abdominal sonography for trauma: evaluation of a half-day curriculum. Annals of Emergency Medicine. 1999;34(4):S106.

21. Robinson N. The focused trauma ultrasound examination. Can, and should, accident and emergency physicians in the UK acquire this skill? Emergency Medicine Journal. 2000;17:330-333.

22. Noble V, Lamhaut L, Capp R, et al. Evaluation of a thoracic ultrasound training module for the detection of pneumothorax and pulmonary edema by prehospital physician care providers. BMC Medical Education. 2009;9:3.

23. Shackford S, Rogers F, Osler T, et al. Focused abdominal sonogram for trauma: the learning curve for nonradiologist clinicians in detecting hemoperitoneum. Journal of Trauma and Acute Care Surgery. 1999;46(4):553-564.

24. Heegard W, Plummer D, Dries D, et al. Ultrasound for the air medical clinician. Air Medical Journal. 2004;23(2):20-23.

25. McCallum J, Vu E, Sweet D, et al. Assessment of paramedic ultrasound curricula: A systematic review. Air Medical Journal. 2015;34 (6):360-368.

26. Walcher F, Kirschning T, Muller MP, et al. Accuracy of prehospital focused abdominal sonography for trauma after a 1-day hands-on training course. Emergency Medicine Journal. 2010; 27:345-349.

27. Kim CH, Shin SD, Song KJ, et al. Diagnostic accuracy of focused assessment with sonography for trauma (FAST) examinations performed by emergency medical technicians. Prehospital Emergency Care. 2012;16(3):400-406.

28. Walcher F, Weinlich M, Conrad G, et al. Prehospital ultrasound improves management of abdominal trauma. British Journal of Surgery. 2005;93(2):238-242.

29. Unluer E, Yavasi O, Kara PH, et al. Paramedic performed focused assessment with sonography in trauma (FAST) in the emergency department. Ulus Travma Acil Cerrahi Derg. 2011;17(2):113-116.

30. Chin E, Chan C, Mortazavi R, et al. A pilot study examining the viability of a prehospital assessment with ultrasound for emergencies (PAUSE) protocol. Journal of Emergency Medicine. 2013;44(1):142-149.

31. Lichtenstein D, Goldstein I, Mourgeon E, et al. Comparative diagnostic performances of auscultation, chest radiography, and lung ultrasonography in acute respiratory distress. Anesthesiology. 2004;100 (1):9-15.

32. Lyon M, Walton P, Bhal la V, et al. Ultrasound detection of the sliding lung sign by pre-hospital critical care providers. American Journal of Emergency Medicine. 2012; 30(3):485-488.

33. Roline CE, Heegaard W, Moore JC, et al. Feasibility of bedside thoracic ultrasound in the helicopter emergency medical services setting. Air Medical Journal. 2013;32(3):153-157.

34. Brooke M, Walton J, Scutt D, et al. Acquisition and interpretation of focused diagnostic ultrasound images by ultrasound-naive advanced paramedics: trialling a PHUS education programme. Emergency Medicine Journal. 2012;29(4):322-326.

35. Raio CC, Modayil V, Cassara M, et al. Can emergency medical services personnel identify pneumothorax on focused ultrasound examinations? Critical Ultrasound Journal. 2009;1(2):65-68.

36. Kimura B. Point-of-care cardiac ultrasound techniques in the physical examination: better at the bedside. Heart. 2017;103:987-994.

37. Littman L, Bustin D, Haley M. A simplified and structured teaching tool for the evaluation and management of pulseless electrical activity. Medical Principles and Practice. 2014;23(1):1-6.

38. Deakin CD, Nolan JP, Soar J, et al. European resuscitation council guidelines for resuscitation 2010 Section 4. adult advanced life support. Resuscitation. 2010;81:1305–1352.

39. Neumar RW, Otto CW, Link MS, et al. Part 8: adult advanced cardiovascular life support: 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation. 2010;122:S729–S767.

40. Engdahl J, Bång A, Lindqvist J, et al. Factors affecting short- and long-term prognosis among 1,069 patients with out-of-hospital cardiac arrest and pulseless electrical activity. Resuscitation. 2001;51(1):17–25.

41. Backlund B, Bonnett C, Faragher J, et al. Pilot study to determine the feasibility of training Army National Guard medics to perform

focused cardiac ultrasonography. Perhospital Emergency Care. 2010:14(1):118-123.

42. Rooney K, Lahham S, Lahham S, et al. Pre-hospital assessment with ultrasound in emergencies: implementation in the field. World Journal of Emergency Medicine. 2016;7(2):117-123.

43. Johri A, Durbin J, Newbigging J, Tanzola R, et al. Cardiac point-of-care ultrasound: state-of-the-art in medical school education. Journal of the American Society of Echocardiography. 2018;7(31):749-760.

44. Ackoff R. Science in the systems age: beyond IE, OR and MS. Operations Research. 1973;21(3):661-865.

45. Emanuel LL, Taylor L, Hain A, et al. Module 1: systems thinking: moving beyond blame to safety. The Patient Safety Education Program (PSEP) Canada. 2017:108-118.

46. Sayed M, Zaghrini E. Prehospital emergency ultrasound: A review of current clinical applications, challenges and future implications. Emergency Medicine International. 2013;2013:1-6.

47. Garrone M. Prehospital ultrasound as the evolution of the Franco-German model of prehospital EMS. Critical Ultrasound Journal. 2011;3 (3):141-147.

48. Heiner J, McArthur T. The ultrasound identification of simulated long bone fractures by prehospital providers. Wilderness & Environmental Medicine. 2010; 21(2):137-140.

49. Rudolph S.S, Sorensen M, Svane C, et al. Effect of prehospital ultrasound on clinical outcomes of non-trauma patients-a systematic review. Resuscitation. 2014:85(1):21-30.