

Crit Ultrasound J (2010) 1:117–122  
DOI 10.1007/s13089-010-0024-5

REVIEW ARTICLE

# Opening Pandora's box: the potential benefit of the expanded FAST exam is partially confounded by the unknowns regarding the significance of the occult pneumothorax

Andrew W. Kirkpatrick · Lawrence M. Gillman ·  
Rosaleen Chun · Chad G. Ball · Corina Tiruta ·  
Rohan Lall · Michael Dunham

Received: 12 December 2009 / Accepted: 5 March 2010 / Published online: 7 April 2010  
© Springer-Verlag 2010

## Abstract

**Introduction** Point of care (POC) ultrasound brings another powerful dimension to the physical examination of the critically ill. A contemporary challenge for all care providers, however, is how to best incorporate ultrasound into contemporary algorithms of care. When POC ultrasound corroborates pre-examination clinical suspicion, incorporation of the findings into decision-making is easier. When POC ultrasound generates new or unexpected findings, decision-making may be more difficult, especially with conditions that were previously not appreciated with older diagnostic technologies. Pneumothoraces (PTXs), previously seen only on computed tomography and not on supine chest radiographs known as occult pneumothoraces (OPTXs), which are now increasingly appreciated on POC ultrasound, are such an example.

**Electronic supplementary material** The online version of this article (doi:[10.1007/s13089-010-0024-5](https://doi.org/10.1007/s13089-010-0024-5)) contains supplementary material, which is available to authorized users.

A. W. Kirkpatrick · C. G. Ball · R. Lall · M. Dunham  
Department of Surgery, Foothills Medical Centre,  
Calgary, AB, Canada

A. W. Kirkpatrick · L. M. Gillman · M. Dunham  
Department of Critical Care Medicine, Foothills Medical Centre,  
Calgary, AB, Canada

A. W. Kirkpatrick (✉) · L. M. Gillman · C. Tiruta · R. Lall ·  
M. Dunham  
Department of Regional Trauma Services, Foothills Medical  
Centre, 1403 29th Street NW, Calgary, AB T2N 2T9, Canada  
e-mail: [andrew.kirkpatrick@calgaryhealthregion.ca](mailto:andrew.kirkpatrick@calgaryhealthregion.ca)

R. Chun  
Department of Anesthesia, Foothills Medical Centre,  
Calgary, AB, Canada

**Methods** The relevant literature concerning POC ultrasound and PTXs was reviewed after an electronic search using PubMed supplemented by ongoing research by the Canadian Trauma Trials Collaborative of the Trauma Association of Canada.

**Results** OPTXs are frequently encountered in the critically injured who often require mechanical ventilation with positive pressure breathing (PPB). Standard recommendations for post-traumatic PTXs and the setting of PPB mandate chest drainage, recognizing a significant rate of complications related to this procedure itself. Whether these standard recommendations generated in response to obvious overt PTXs apply to these more subtle OPTXs is currently unknown, and evidence-based recommendations regarding appropriate therapy are impossible due to the lack of clinical studies.

**Conclusions** OPTXs are a condition that illustrates how incorporation of POC ultrasound findings brings further responsibilities to critically appraise the significance of these findings in terms of patient outcomes and overall care. Adequately powered and adequately followed-up clinical trials addressing the treatment are required.

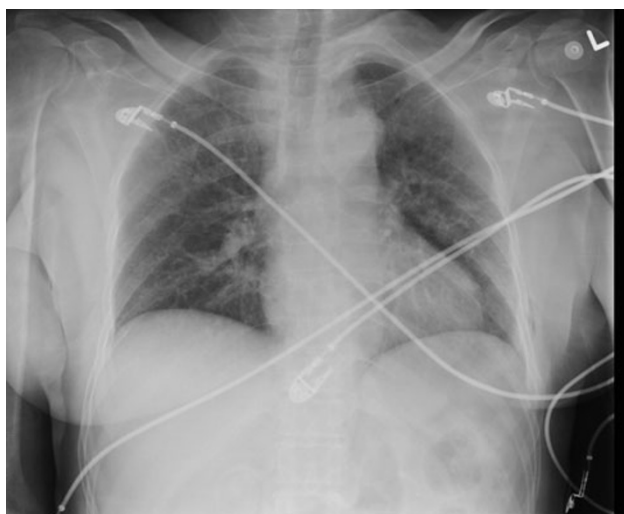
**Keywords** Point of care ultrasound · Critical ultrasound · Pneumothorax · Occult pneumothorax · Critical care · Mechanical ventilation

## Introduction

Ultrasound is rapidly being accepted as an indispensable tool that adds another dimension to almost any clinical encounter [1, 2]. As a result of its ability to interrogate anatomy deep within the body, ultrasound may provide information and yield diagnoses that would not be



**Fig. 1** CT scan of acutely injured patient reveals a pneumothorax not previously seen on the AP supine chest radiograph



**Fig. 2** AP supine chest radiograph of the patient in Fig. 1, without any obvious indication of a PTX

identified using either physical examination or sometimes even standard bedside radiologic tests. Pneumothoraces (PTXs), seen on ultrasound (potentially confirmed using CT scan if necessary), but not seen on the standard AP supine chest radiograph are termed occult pneumothoraces (OPTX) (i.e., occult to the CXR) [3–5] (Figs. 1, 2). With continued study, it is now recognized that in busy trauma centers the majority of PTXs encountered in the critically injured may be occult [6, 7]. However, point of care (POC) ultrasound has recently been shown to be an excellent modality for detecting this condition [8–10]. The defining

factor of POC ultrasound is the fact that it is clinician-performed and immediate. However, with information comes responsibility for information management and interpretation. The new information that the clinician now possesses regarding the presence of an OPTX, that is unexpected both clinically and previously unknown radiologically, presents a quandary. Should the clinician ignore this finding, recognizing that in previous years they would have never known about it, or should they treat it with placement of an early chest drain? Unfortunately this intervention carries serious potential side effects [11, 12]. The answer is unclear, but the question exemplifies how the incorporation of ultrasound as a new standard of physical examination will bring new challenges regarding the need for evidence-based ultrasound-guided clinical pathways to appropriately incorporate these findings to ensure optimal patient care [13].

### The examination: the expanded FAST examination

The focused assessment with sonography for trauma (FAST) has become a widely accepted and valuable tool for resuscitating patients with traumatic injury [14, 15]. A benefit of the increasing adoption of ultrasound (US) as an everyday tool used by clinicians to assess the critically ill and injured has been a natural curiosity to expand the scope of conditions being sought [2, 16]. The use of US to diagnose the presence of pneumothoraces (PTX) is one such example, leading to the concept of the expanded or EFAST [9, 17]. The healthy lung itself is not an obvious target organ for examination with US. As air has a very high acoustic reflectance, only artifacts are normally identified deep-normal pleural surfaces [18]. Thus, the majority of life-threatening post-traumatic thoracic trauma is pleural based. These include rib fractures, flail chests, hemothoraces, and PTX [19, 20]. The physiologic pleural movements that occur with respiration, either spontaneous or assisted, are therefore accurately and quickly depicted using simple bedside US [21–23].

The concept of employing US to exclude or infer the presence of a PTX relies on the fact that if the pleural surfaces are proven to be in apposition, then by definition an intra-pleural collection of air is excluded. For this physiologic “lung sliding” (LS) to be seen, both pleural surfaces must be accessible to be imaged, and thus must be either contiguous or separated by a layer of fluid [9, 21, 23–25]. In PTX, the intra-pleural air will separate the two pleural surfaces and lung sliding will not be identified since the visceral pleura are inaccessible to the US beam. With a PTX, the images seen are horizontal reverberation artifacts with no evidence of LS. Besides LS, another US finding also affects the confidence of diagnosis. “Comet tail”

artifacts (CTA) are reverberations believed to arise from distended water-filled interlobular septae under the visceral pleura. These are presumed to be the US equivalents of the “Kerley B lines” seen on CXR [26, 27] as they can only be seen when the visceral pleura is in apposition to the parietal pleura.

Other simple diagnostic maneuvers providing further diagnostic confidence have been described. The color power Doppler function is a simple technical means of visually enhancing the depiction of sliding, designated the “Power Slide” [28]. This feature therefore allows a single still image to depict a dynamic physiologic process, thus simplifying archiving, transmission, and possibly even auto-interpretation [29]. The utilization of the time–motion or *M* mode function is another means of depicting and enhancing lung sliding as a static image [8, 25, 30]. The “seashore sign” represents a granular pattern generated by the normal pleural movements. In the presence of a pneumothorax, however, the stratospheric sign is produced instead, as there are no pleural movements upon one another. The lung point sign builds upon these two previous signs to describe that point on the chest wall at which the underlying lung intermittently contacts the chest wall (Fig. 3). Thus, the US image will alternate between the seashore and the stratosphere signs, allowing one to actually discern the size of a pneumothorax [25, 30–32].

Using this diagnostic approach, numerous investigators have begun to use ultrasound to diagnose the presence of pneumothoraces. Initial studies explored the potential of US to infer the presence of pneumothoraces in veterinary settings [33], after lung biopsies [18, 34, 35], and in a mixed group that included three stable trauma patients [22]. Much of the pioneering work arose from Dr. Lichtenstein’s [21, 24, 26] group in Paris. North American



**Fig. 3** Point of care bedside ultrasound revealing an example of a lung point wherein a portion of lung intermittently appears within the ultrasound appearance of a PTX which indicates the lateral extent on the chest wall of the PTX. As is typical of all POC ultrasound diagnoses, this phenomenon is better viewed in real-time video sequence (see electronic supplementary material)

interest in this technique was greatly facilitated by specific space medicine-related needs arising from the presence aboard the International Space Station of a high quality ultrasound capability, without any other medical diagnostic capabilities. NASA-associated research thus examined basic science and clinical questions both in terrestrial- and space-analog environments [23, 29, 36–42]. In the course of these investigations it became apparent that there were frequently cases whereby ultrasound appeared to be more sensitive in detecting pneumothoraces after trauma than the supine chest radiograph [8–10, 23, 43]. One study utilizing the EFAST during acute trauma resuscitations found that in patients with CT corroboration, the expanded FAST was more than twice as sensitive as supine chest X-ray [9]. Since this study, other authors have also reported remarkably high accuracies for detecting OPTXs [8, 44], and have even documented good correlation between the estimated PTX size and the CT findings (Spearman’s rank correlation 0.82) using the relative thoracic topography of lung sliding [44].

### The condition: occult pneumothoraces

It should not be surprising that ultrasound appears to outperform the supine chest radiograph in terms of diagnosing post-traumatic pneumothoraces. This is because of the ever increasingly recognized phenomenon of the occult pneumothorax (OPTX) [3]. This term describes a pneumothorax (PTX) that while not suspected on the basis of either clinical examination or plain radiograph, but is ultimately detected with thoraco-abdominal computed tomogram (CT) [3, 4, 6, 7, 45, 46]. This situation is increasingly common with the increased use of CT. The incidence appears to approximate 5% in injured populations presenting to hospital [45, 47–52], with CT revealing at least twice as many PTXs as suspected on plain radiographs [43, 47, 50, 52–56].

### The clinical quandary: what to do with occult pneumothoraces?

The EFAST technique provides a means of detecting many OPTXs that would have been missed if only supine CXRs were being obtained, or diagnosed in a delayed fashion if CT scans were obtained in all traumatized patients. An earlier diagnosis might be especially beneficial in pre-hospital and air transport environments [17, 57]. Though the patient is admitted to a hospital setting, the importance of detecting OPTXs remains largely unknown because the clinical importance of OPTXs themselves remains somewhat unclear and controversial [3, 58]. While PTXs are a

common and treatable cause of mortality and morbidity, there is clinical equipoise regarding the appropriate treatment of the OPTX [3, 58]. This is especially true in those who are critically ill and require positive pressure ventilation (PPV). This is also the group for whom the highest rates of chest tube complications have been reported [12]. More specifically, complication rates related to tube thoracostomy have been reported in up to 21% of cases [11, 12, 59, 60]. While the patient undergoing PPV is at the greatest risk, proper management of an OPTX is extremely controversial and based on little scientific evidence. Many of these patients are already compromised due to acquired or pre-existing pulmonary pathology, and clinical respiratory distress may be masked by concomitant respiratory support and sedation. Conversely, these patients are constantly monitored and cared for in settings where immediate medical intervention is possible. Kollöff [61] also reported that ventilated patients with PTXs were statistically more likely to develop tension pneumothoraces when the diagnosis was missed or delayed. The guidelines of the Advanced Trauma Life Support Course state that general anesthesia or positive pressure ventilation should never be administered to a patient who has sustained a traumatic pneumothorax, or who is at risk for an unexpected pneumothorax, without chest tube insertion [19]. The potential risk of progression of a known PTX, to a tension PTX, is thus a significant concern, with many opinions recommending prophylactic chest tube placement for the patient who is subjected to positive pressure ventilation [45, 47, 53, 54, 62–64].

However, other sources differ. In one review, the size of the OPTX and number of rib fractures indirectly affected outcome by influencing when clinicians placed chest tubes [49]. If an OPTX was less than 5 mm × 80 mm, and associated with two or less rib fractures, patients were managed conservatively, irrespective of the need for ventilation. Ten of 17 (59%) total patients managed without chest tubes were intubated and ventilated with positive pressures. None required emergency chest tube, although three of these ten (30%) ultimately required tube thoracostomy for progression of their PTX [49]. Another retrospective review of 26 patients compared the characteristics and outcomes of 13 who were observed with repeated chest radiography and 11 who underwent early chest tube [65]. Ten of the 26 were ventilated, of which six were managed without a chest tube. Despite the fact that one of these (17%) failed observation (PTX progression), they concluded that there was no indication of an OPTX warranted a prophylactic chest tube prior to positive pressure ventilation [65]. Wolfman observed OPTX's in 36 patients. Thirteen of 16 "miniscule" occult PTXs, and 11 of 20 moderate (anterior) PTXs were managed successfully without chest tube for a 11%

failure rate of observation, including one tension pneumothorax [66]. The eight remaining antero-lateral PTXs were all treated with tube thoracostomy, whether intubated or not. They concluded that only small and moderate occult PTXs without mechanical ventilation could be safely observed based on their results as they had not randomized the larger OPTXs [66]. Guerrero-Lopez [55] stated that OPTXs did not always necessitate treatment despite mechanical ventilation, if they were "small and without complications".

The best, although very limited, evidence guiding management of occult PTXs in ventilated patients originates from two small prospective randomized studies. Enderson [5] randomized 40 patients with occult PTXs to chest tube [19] or observation [21], regardless of mechanical ventilation. Fifteen observed patients were ventilated, as were 12 with early chest tubes. Eight of the 15 (53%) had pneumothorax progression with ventilation, three suffering tension PTXs. As none of the patients with tube thoracostomy suffered any major complication, they recommended that all patients with OPTX, who require mechanical ventilation, have chest tubes placed. They felt that the size of the initial OPTX was not predictive of the risk of a tension PTX. Conversely, in 1999, Brasel [51] reported on a prospective randomized trial in 39 blunt trauma patients with 44 occult PTX's. Nine patients in each group were ventilated, and there was no statistical difference in the sizes of OPTX's. There were no differences in complications, and no patients in either group required emergent tube thoracostomy for respiratory compromise. Given the small numbers, this neither reach statistical significance, nor was there any association between size of the OPTX and failure of conservative treatment [58]. They concluded, however, that OPTX's could be safely observed in ventilated patients. When critically appraised, the power of these small studies was insufficient to truly detect differences [58]. If a true difference existed between these studies, another explanation for the potential discordance might also involve differences in ventilatory management, as most of latter patients were in the intensive care unit and most of former were in the operative suite. Approaches to ventilation strategies in general also changed significantly over the last decade. Decreased airway pressures and tidal volumes became routine in the critically ill, wherein ventilatory management stressed careful attention to controlling peak and mean airway pressures, and limiting pressures below those considered routine previously [67–69]. To further address this clinical question, the Canadian Trauma Trials Collaborative of the Trauma Association of Canada has initiated a multi-center prospective randomized trial of treating or observing selected mechanically ventilated patients with OPTXs [70].

## Is POC ultrasound the hope at the bottom of Pandora's box?

Pandora had been given a large jar (rather than a box) and instruction by Zeus to keep it closed, but she had also been given the gift of curiosity, and ultimately opened it. When she did so, all of the evils, ills, diseases, and burdensome labor that mankind had not known previously, escaped from the jar, but it is said, that at the very bottom of her jar, there lay hope [71]. We do believe that there definitely is hope, at the bottom of the unknowns, potential misdiagnoses, and iatrogenic harm that may occur from knowing without understanding, and that POC ultrasound is simply the latter—understanding our patients better. This understanding occurs on many levels, however, such as having a greater fidelity of imaging. No longer does a PTX need to be simply there or not there. POC ultrasound has the ability to discern in real-time how big in terms of chest topography the PTX is, and whether it is expanding or decreasing in size [44, 72]. This understanding also requires detailed studies on outcomes; now that we will know more about our patients; we need to know what matters and what does not. It is in this realm that evidence-based medicine becomes critical.

### Conclusion

At the present time, the EFAST examination is able to identify previously undetected pneumothoraces after injury in our sickest patients. The question remains though, how does this help them? Are occult pneumothoraces important or will we injure more patients by acting on this information and draining all the pleural spaces concerned? Only well constructed and conducted prospective research appropriately related to the overall clinical needs of the patient can answer this [13]. Until these results are available, however, we would suggest that awareness and respect for the power of ultrasound as knowledge rather than ignorance of the unknown are the first and hopeful step in understanding.

**Acknowledgments** This work has been supported in part by the Derek Thompson Memorial grant from the Canadian Intensive Care Foundation and in part by the Research Committee of the Trauma Association of Canada.

**Conflict of interest** None.

### References

- Blaivas M (2009) A new point of care ultrasound journal. *Crit Ultrasound J* 1:1–2
- Kirkpatrick AW, Sustic A, Blaivas M (2007) Introduction to the use of ultrasound in critical care medicine. *Crit Care Med* 35:S223–S225
- Ball CG, Hameed SM, Evans D et al (2003) Occult pneumothorax in the mechanically ventilated trauma patient. *Can J Surg* 46:373–379
- Ball CG, Kirkpatrick AW, Feliciano DV (2009) The occult pneumothorax: what have we learned? *Can J Surg* 52:E173–E179
- Enderson BL, Abdalla R, Frame SB et al (1993) Tube thoracostomy for occult pneumothorax: a prospective randomized study of its use. *J Trauma* 35:726–730
- Ball CG, Kirkpatrick AW, Laupland KB et al (2005) Incidence, risk factors, and outcomes for occult pneumothoraces in victims of major trauma. *J Trauma* 59:917–924 (discussion 924–915)
- Ball CG, Ranson K, Dente CJ et al (2009) Clinical predictors of occult pneumothoraces in severely injured blunt polytrauma patients: a prospective observational study. *Injury* 40:44–47
- Lichtenstein DA, Meziere G, Lascols N et al (2005) Ultrasound diagnosis of occult pneumothorax. *Crit Care Med* 33:1231–1238
- Kirkpatrick AW, Sirois M, Laupland KB et al (2004) Hand-held thoracic sonography for detecting post-traumatic pneumothoraces: the Extended Focused Assessment with Sonography for Trauma (EFAST). *J Trauma* 57:288–295
- Kirkpatrick AW, Ng AK, Dulchavsky SA et al (2001) Sonographic diagnosis of a pneumothorax inapparent on plain radiography: confirmation by computed tomography. *J Trauma* 50:750–752
- Ball CG, Lord J, Laupland KB et al (2007) Chest tube complications: how well are we training our residents? *Can J Surg* 50:450–458
- Etoch SW, Bar-Natan MF, Miller FB et al (1995) Tube thoracostomy: factors related to complications. *Arch Surg* 130:521–526
- Elbarbary M (2009) Evidence-based critical ultrasound: a mission possible. *Crit Ultrasound J* 1:3–4
- Hoff WS, Holevar M, Nagy KK et al (2002) Practice management guidelines for the evaluation of blunt abdominal trauma: the East practice management guidelines work group. *J Trauma* 53:602–615
- Melniker LA, Leibner E, McKenney MG et al (2006) Randomized controlled trial of point-of-care, limited ultrasonography for trauma in the emergency department: the first sonography outcomes assessment program trial. *Ann Emerg Med* 48:227–235
- Blaivas M, Kirkpatrick A, Sustic A (2007) Future directions and conclusions. *Crit Care Med* 35:S305–S307
- Kirkpatrick AW, Breeck K, Wong JL et al (2005) The potential of hand-held trauma sonography in the air medical transport of the trauma victim. *Air Med J* 24:34–39
- Sistrom CL, Reiheld CT, Gay SB et al (1996) Detection and estimation of the volume of pneumothorax using real-time sonography: efficacy determined by receiver operating characteristic analysis. *AJR* 166:317–321
- Trauma ACoSCo (2008) Thoracic trauma. In: *Advanced trauma life support student course manual*. American College of Surgeons, Chicago, pp 85–110
- Richardson JD, Miller FB (1996) Injury to the lung and pleura. In: Feliciano DV, Moore EE, Mattox KL (eds) *Trauma*. Appleton & Lange, Stamford, pp 387–407
- Lichtenstein DA, Menu Y (1995) A bedside ultrasound sign ruling out pneumothorax in the critically ill: lung sliding. *Chest* 108:1345–1348
- Wernecke K, Galanski M, Peters PE et al (1987) Pneumothorax: evaluation by ultrasound-preliminary results. *J Thorac Imaging* 2:76–78
- Dulchavsky SA, Schwarz KL, Kirkpatrick AW et al (2001) Prospective evaluation of thoracic ultrasound in the detection of pneumothorax. *J Trauma* 50:201–205
- Lichtenstein DA (2002) Pneumothorax and introduction to ultrasound signs in the lung. In: Lichtenstein DA (ed) *General Ultrasound in the critically ill*. Springer, Berlin, pp 105–115
- Lichtenstein DA (2007) Ultrasound in the management of thoracic disease. *Crit Care Med* 35:S250–S261

26. Lichtenstein D, Meziere G, Biderman P et al (1999) The comet-tail artifact: an ultrasound sign ruling out pneumothorax. *Intensive Care Med* 25:383–388
27. Lichtenstein D, Meziere G, Biderman P et al (1997) The comet-tail artifact: an ultrasound sign of alveolar-interstitial syndrome. *Am J Respir Crit Care Med* 156:1640–1646
28. Cunningham J, Kirkpatrick AW, Nicolaou S et al (2002) Enhanced recognition of “lung sliding” with power color Doppler imaging in the diagnosis of pneumothorax. *J Trauma* 52:769–771
29. Kirkpatrick AW, Nicolaou S, Rowan K et al (2005) Thoracic sonography for pneumothorax: the clinical evaluation of an operational space medicine spin-off. *Acta Astronaut* 56:831–838
30. Kirkpatrick AW (2007) Clinician-performed focused sonography for the resuscitation of trauma. *Crit Care Med* 35:S162–S172
31. Lichtenstein D, Meziere G, Biderman P et al (2000) The “lung point”: an ultrasound sign specific to pneumothorax. *Intensive Care Med* 26:1434–1440
32. Gillman LM, Alkadi A, Kirkpatrick AW (2009) The “pseudo-lung point” sign: all focal respiratory coupled alternating pleural patterns are not diagnostic of a pneumothorax. *J Trauma* 67:672–673
33. Rantanen NW (1986) Diagnostic ultrasound: diseases of the thorax. *Vet Clin North Amer* 2:49–66
34. Targhetta R, Bourgeois JM, Chavagneux R et al (1992) Diagnosis of pneumothorax by ultrasound immediately after ultrasonically guided aspiration biopsy. *Chest* 101:855–856
35. Goodman TR, Traill ZC, Phillips AJ et al (1999) Ultrasound detection on pneumothorax. *Clin Radiol* 54:736–739
36. Dulchavsky SA, Hamilton DR, Diebel LN et al (1999) Thoracic ultrasound diagnosis of pneumothorax. *J Trauma* 47:970–971
37. Sargsyan AE, Hamilton DR, Nicolaou S et al (2001) Ultrasound evaluation of the magnitude of pneumothorax: a new concept. *Am Surg* 67:232–235 (discussion 235–236)
38. Kirkpatrick AW, Hamilton DR, Nicolaou S et al (2003) Focused assessment with sonography for trauma in weightlessness: a feasibility study. *J Am Coll Surg* 196:833–844
39. Hamilton DR, Sargsyan AE, Kirkpatrick AW et al (2004) Sonographic detection of pneumothorax and hemothorax in microgravity. *Aviat Space Environ Med* 75:272–277
40. Sargsyan AE, Hamilton DR, Jones JA et al (2005) FAST at MACH 20: clinical ultrasound aboard the International Space Station. *J Trauma* 58:35–39
41. Jones JA, Kirkpatrick AW, Hamilton DR et al (2007) Percutaneous bladder catheterization in microgravity. *Can J Urol* 14:3493–3498
42. Kirkpatrick AW, Nicolaou S, Campbell MR et al (2002) Percutaneous aspiration of fluid for management of peritonitis in space. *Aviat Space Environ Med* 73:925–930
43. Rowan KR, Kirkpatrick AW, Liu D et al (2002) Traumatic pneumothorax detection with thoracic US: correlation with chest radiography and CT—initial experience. *Radiology* 225:210–214
44. Blaivas M, Lyon M, Duggal S (2005) A prospective comparison of supine chest radiography and bedside ultrasound for the diagnosis of traumatic pneumothorax. *Acad Emerg Med* 12:844–849
45. Wall SD, Federle MP, Jeffrey RB et al (1983) CT diagnosis of unsuspected pneumothorax after blunt abdominal trauma. *Am J Radiol* 141:919–921
46. Ball CG, Kirkpatrick AW, Fox DL et al (2006) Are occult pneumothoraces truly occult or simply missed? *J Trauma* 60:294–298 discussion 298–299
47. Rhea JT, Novelline RA, Lawrason J et al (1989) The frequency and significance of thoracic injuries detected on abdominal CT scans of multiple trauma patients. *J Trauma* 29:502–505
48. Hill SL, Edmisten T, Holtzman G et al (1999) The occult pneumothorax: an increasing entity in trauma. *Am Surg* 65:254–258
49. Garramone RR, Jacob LM, Sahdev P (1991) An objective method to measure and manage occult pneumothoraces. *Surg Gyne Obs* 173:257–261
50. Wolfman NT, Gilpin JW, Bechtold RE et al (1993) Occult pneumothorax in patients with abdominal trauma: CT studies. *J Comput Assist Tomogr* 17:56–59
51. Brasel KJ, Stafford RE, Weigelt JA et al (1999) Treatment of occult pneumothoraces from blunt trauma. *J Trauma* 46:987–991
52. Neff MA, Monk JS, Peters K et al (2000) Detection of occult pneumothoraces on abdominal computed tomographic scans in trauma patients. *J Trauma* 49:281–285
53. Tocino IM, Miller MH, Frederick PR et al (1984) CT detection of occult pneumothoraces in head trauma. *Am J Roentgenol* 143:987–990
54. Trupka A, Waydhas C, Hallfeldt KKJ et al (1997) Value of thoracic computed tomography in the first assessment of severely injured patients with blunt chest trauma: results of a prospective study. *J Trauma* 43:405–412
55. Guerrero-Lopez F, Vasquez-Mata G, Alcazar-Romero P et al (2000) Evaluation of the utility of computed tomography in the initial assessment of the critical care patient with chest trauma. *Crit Care Med* 28:1370–1375
56. Holmes JF, Brant WE, Bogren HG et al (2001) Prevalence and importance of pneumothoraces visualized on abdominal computed tomographic scan in children with blunt trauma. *J Trauma* 50:516–520
57. Kirkpatrick AW, Brown DR, Crickmer S et al (2001) Hand-held portable sonography for the on-mountain exclusion of a pneumothorax. *Wilderness Environ Med* 12:270–272
58. Kirkpatrick AW, Stephens M, Fabian T (2006) Canadian Association of General Surgeons and American College of Surgeons Evidence Based Reviews in Surgery. 18. Treatment of occult pneumothoraces from blunt trauma. *Can J Surg* 49:358–361
59. Millikan JS, Moore EE, Steiner E et al (1980) Complications of tube thoracostomy for acute trauma. *Am J Surg* 140:738–741
60. Bailey RC (2000) Complications of tube thoracostomy in trauma. *J Accid Emerg Med* 17:111–114
61. Kollef MH (1991) Risk factors for the misdiagnosis of pneumothorax in the intensive care unit. *Crit Care Med* 19:906–910
62. Bridges KG, Welch G, Silver M et al (1993) CT diagnosis of occult pneumothoraces in multiple trauma patients. *J Emerg Med* 11:179–186
63. Karnik AM, Khan FA (2001) Pneumothorax and barotrauma. In: Parillo JE, Dellinger RP (eds) *Critical care medicine: principles of diagnosis and management in the adult*. Mosby, St. Louis, pp 930–948
64. Omert L, Yeane WW, Protech J (2001) Efficacy of thoracic computerized tomography in blunt chest trauma. *Am Surg* 67:660–667
65. Collins JC, Levine G, Waxman K (1992) Occult traumatic pneumothorax: immediate tube thoracostomy versus expectant management. *Am Surg* 58:743–746
66. Wolfman NT, Myers MS, Glauser SJ et al (1998) Validity of CT classification on management of occult pneumothorax: a prospective study. *Am J Roentgenol* 171:1317–1323
67. ARDS Network (2000) Ventilation with lower tidal volumes as compared with traditional volumes for acute lung injury and the acute respiratory distress syndrome. *N Engl J Med* 342:1301–1308
68. Pinhu L, Whitehead T, Evans T et al (2003) Ventilator-associated lung injury. *Lancet* 361:332–340
69. Kirkpatrick AW, Meade MO, Mustard RA et al (1996) Strategies of invasive ventilatory support in ARDS. *Shock* 6:S17–S22
70. Ouellet JF, Trottier V, Kmet L et al (2009) The OPTICC trial: a multi-institutional study of occult pneumothoraces in critical care. *Am J Surg* 197:581–586
71. Wikipedia Inc. (2010) Pandora’s box. Available at: [http://en.wikipedia.org/wiki/Pandora's\\_box](http://en.wikipedia.org/wiki/Pandora's_box). Accessed 12 Jan 2010
72. Soldati G, Testa A, Sher S et al (2008) Occult traumatic pneumothorax: diagnostic accuracy of lung ultrasonography in the emergency department. *Chest* 133:204–211