Where Does Innovation in Critical Care Ultrasound Come From? Perhaps a Look in the Mirror*

In the field of observation chance favors only the prepared mind.–Louis Pasteur, University of Lille, 1854 (1)

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In 1956, while working on a pursuing idea for a fast heart rhythm recorder, American inventor William Greatbatch reached into a box of resistors and mistakenly installed one of incorrect size. When he turned it on, he noticed that the circuit emitted electrical pulses instead of recording them. In a moment of clarity, Greatbatch realized that this device could pace a human heart (2, 3). The modern implantable cardiac pacemaker was born. In the history of medicine, careful observation leading to innovation has played a critical role in many discoveries. These include nitrous oxide as anesthesia, the smallpox vaccination, x-ray imaging, penicillin, and warfarin among others. Prior to 1992, it was a common belief that lung ultrasound was unfeasible as air interferes with ultrasound transmission. That year Lichtenstein (4), a medical intensivist at the Ambroise-Paré Hospital near Paris, France, first reported associations between lung ultrasound findings and lung parenchymal disease as well as pneumothorax. Despite facing the inertia of imaging philosophy discouraging lung ultrasound at the time, his findings spawned a new diagnostic application and the dawn of the discipline of lung ultrasound. A National Library of Medicine website literature search for lung or pulmonary ultrasound today yields over a thousand citations.

In this issue of *Pediatric Critical Care Medicine*, Küng et al (5) suggest the finding of a lung ultrasound artifact, mirrored ribs, as being highly sensitive and specific for the diagnosis of pneumothorax. Uniting the phenomenon of pleural mirroring in pneumothorax and the imaging characteristics of incompletely ossified ribs in neonates, the authors present the first series to date examining the diagnostic utility of rib mirroring as an indicator for pneumothorax. Also having been described as "figure-of-eight sign" (6), the finding appears as exact mirroring of the ovoid cartilaginous ribs of the neonate across the pleura in pneumothorax appearing as a series of "eights." The mirroring phenomenon occurs due to stark density differences between pneumothorax air and tissues of the chest wall causing ultrasound reflection at the pleural boundary. Due to lengthening of the ultrasound beam as it rebounds between the probe and pleural line, the machine believes that reflections are deeper than reality when the beam returns to the probe. This results in the mirrored image tissue findings seen distal to the pleural line (**Fig. 1**). As the authors mention existing signs for pneumothorax require some degree of pleural movement to help rule out pneumothorax. In contrast, the appearance of mirrored ribs would not necessarily require movement and could add to the diagnostic sensitivity of the pneumothorax assessment. This method could be particularly applicable to the neonatal patient, as lung ultrasound is sensitive in rapid pneumothorax evaluation when compared with chest radiograph as demonstrated in a study by Raimondi et al (7) and could reduce the burden of radiation in this vulnerable population. Although the study by Küng et al (5) demonstrated perfect sensitivity and specificity compared with lung ultrasound, it was performed retrospectively in a cohort of patients where ultrasound already confirmed the primary diagnosis. Larger series identifying the utility of the mirrored rib finding prospectively, across a variety of pleural pathologies, are warranted.

Even as authors who have written on this topic, examining these data pragmatically and carefully is appropriate since the clinical relevance of mirrored ribs remains to be determined. However, similarly to other innovations in medicine, the history of lung ultrasound is one where published discoveries lead to cultivated ideas. Despite novel healthcare technologies being a more than $4 billion dollar industry yearly involving 400–600 startups per year, the prevailing majority of these businesses fail (8). This constitutes a high resource cost that is continually driven by inspired thinking seen throughout

*See also p. e944.

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perception that it is doing so without oversight (9). Whether this is true is highly debatable given established certification and guidance mechanisms in place; however, the onus is on POCUS to prove its mettle in terms of accuracy and for the clinician to play a role in this. Additional methods to verify the veracity of POCUS findings in a safe manner can be introduced into protocols and help cement POCUS reliability in comparison to other diagnostic methods including those involving ionizing radiation.

Careful observation led to identification of the benefits of the first pacemaker and an implicit understanding of how physiology could interact with the findings. This was also the case with lung ultrasound as new disciplines have evolved in imaging. As a means of further confirming pneumothorax, it has the potential to be an important part of critical management that reduces the threat of time to imaging and radiation. We need to be aware and cognizant of the changes ahead and the clues at hand that may lead us in new and important discoveries, and it is up to critical care to set the pace.

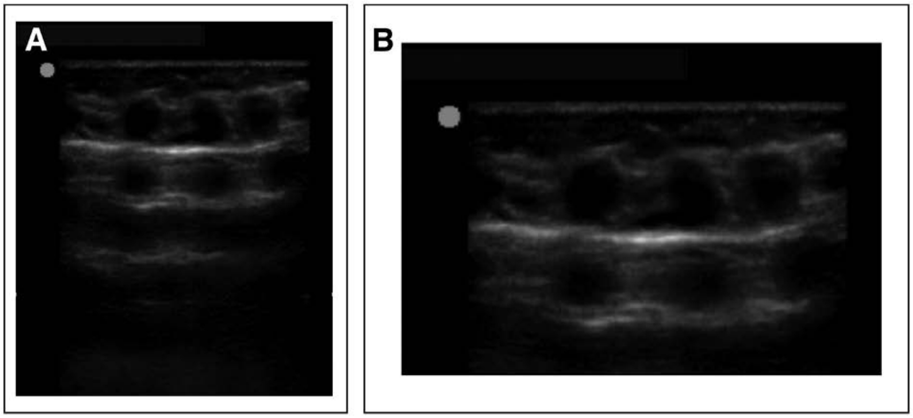

Figure 1. Pneumothorax visualized by ultrasound; "mirrored ribs" or "figure-eight" sign in the left anterior chest. **A**, Four-mo-old congenital diaphragmatic hernia patient receiving high frequency oscillatory ventilation. **B**, Typical appearance of immature ribs in the sagittal plane in the left anterior chest, 4-mo-old with pneumonia and pleural effusion (Review of cases waived by the UT Health Committee for the Protection of Human Subjects).

medicine. Multiple factors have been cited; however, it seems clear that novel endeavors in medicine face a spectrum of challenges in the healthcare environment. Even 6 decades ago, it took William Greatbatch 4 years before his first pacemaker was implanted in a patient, after building around 50 prototypes and years of unemployment at personal cost.

The initial startup expenditure for ultrasound can be substantial, with many point-of-care devices costing in the neighborhood of $30,000–70,000. However, after an initial investment operational costs can be modest affording the clinician ready access to nonirradiating bedside ultrasound imaging with the fidelity of many diagnostic machines. This quality of imaging empowers the bedside clinician to detect imaging signs better and understand clinical findings at the time of symptomatology, which is not always a reasonable expectation of diagnostic imaging services. In this sense, it is an opportunity, and potentially a frontier, for medical discovery.

Given that sensitivity of ultrasound for pneumothorax exceeds 90% in some studies and is thought to surpass chest radiograph in terms of efficacy, one naturally asks why this methodology is necessary. Despite this vaunted superiority, neither multicenter trials nor clinical guidelines advocate for the independent use of ultrasound for pneumothorax detection. Lung ultrasound does not yet enjoy the same traditional acceptance or widespread adoption in medicine as other imaging modalities. This comes at a time when increasing attention is being paid to the oversight of ultrasound and its training. In January 2020, the Joint Commission endorsed a statement that point-of-care ultrasound (POCUS) represents a significant hazard to patients due to its expansion in scope with the unproven

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