Journal of Anesthesia (2019) 33:435–440
https://doi.org/10.1007/s00540-019-02654-0

SPECIAL ARTICLE

Perioperative point of care ultrasound in pediatric anesthesiology: a case series highlighting real-time intraoperative diagnosis and alteration of management augmenting physical examination

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Received: 25 February 2019 / Accepted: 2 May 2019 / Published online: 10 May 2019

Abstract
Use of diagnostic point of care ultrasound, has come to the forefront of interest within anesthesiology. Much data on the use of point of care ultrasound in emergency medicine and critical care medicine for diagnosis and treatment in acute situations exists. While use of point of care ultrasound has become more prevalent in anesthesia practice, documentation of its use and especially alteration in management based on real-time ultrasound findings in the perioperative period remains scarce. This case series discusses six pediatric patients in which real-time intra-operative use of point of care ultrasound resulted in alteration of management.

Keywords Ultrasound · Point of care ultrasound · Perioperative · Pediatric · Cardiac · Transthoracic

Introduction

Point of care ultrasound, which is well established in acute care fields, particularly emergency and critical care medicine, has become particularly relevant to anesthesiology in recent years. While the body of literature related to POCUS for anesthesia is growing, few studies have document actual perioperative use [1, 2]. Moreover, documentation of intra-operative POCUS utilization for augmenting clinical management decisions remains rare, specifically in pediatric patients [3, 4]. This case series presents six patients for which intraoperative anesthesiologist performed point of care ultrasound and helped guide patient management. The aim is to highlight situations in which the anesthesia provider would benefit from the addition of POCUS in real-time as an adjunct to traditional examination.

Case descriptions

Case 1

A 19-year-old female was transferred from an outside institution for management of a tracheoesophageal fistula (TEF) located immediately proximal to the carina. The TEF developed secondarily from tracheal erosion resulting from a prolonged indwelling endotracheal tube. The patient was brought to the operating room for placement of a tracheostomy tube. Due to the close proximity of the TEF to the carina, an adjustable Shiley distal XLT double-cannula tracheostomy tube was planned. This specific tracheostomy allows for adjustment to the intra-tracheal segment length to maintain two lung ventilation. The tracheostomy tube was inserted into the tracheal stoma, however, it was difficult to categorically determine if bilateral lung ventilation was occurring with auscultation alone due to loud and course rhonchi. Flexible bronchoscopy was limited due to extreme ventilatory requirements including positive end expiratory

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00540-019-02654-0) contains supplementary material, which is available to authorized users.

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pressure of 18 cm H_2O leading to severe desaturation limiting the ability to make fine tracheostomy tube length adjustments using bronchoscopy. Initially, the left lung was thought to be ventilated by auscultation. Intraoperative anesthesiologist performed point of care lung ultrasound provided real-time assessment of lung segmental ventilation using the Sonosite (Fujifilm, Bothell, WA) (Video 1). Ultrasound of left lung over the anterior chest in the mid axillary line revealed presence of lung pulsation in the opposing visceral and parietal pleura and absent lung sliding. The tracheostomy tube was retracted until bilateral lung sliding was evident.

Case 2

A 2-year-old, 98 cm, 12.7 kg child with a pleuropulmonary blastoma was brought to the operating room for left lower lobectomy. Three weeks prior, the surgery was aborted after the right lung was contaminated with pus during decubitus positioning despite one lung ventilation. The patient was treated with IV and oral antibiotics prior to reattempting surgical resection. During the repeat surgical attempt, to ensure ventilation of the right lung as well as attempt to prevent spillage of infectious secretions into the non-surgical lobes, a right mainstem intubation was performed and in addition, a 5F Arndt extraluminal bronchial blocker (Cook Medical, Bloomington, IN) was deployed in the left lower lobe bronchus. To confirm placement of the bronchial blocker within the left lower lobe bronchus, anesthesia point of care ultrasound was performed. Ultrasound allowed for visualization of ventilation of the left upper lobe (lung sliding) and absence of ventilation of the left lower lobe (absence of lung sliding and presence of lung pulse (Video 1). Lung ultrasound revealed ventilation of the right upper lobe (lung sliding on the anterior chest, midaxillary line immediately beneath the clavicle) and right lower lobe (lung sliding at the costal margin in the midclavicular and midaxillary lines). Ultrasound confirmation of ventilation was re-confirmed once the patient assumed right lateral decubitus positioning.

Case 3

An 8-year-old female presented for diagnostic bronchoscopy to evaluate her arytenoid cartilage. Born at 23 weeks of gestation, she required tracheostomy following prolonged endotracheal intubation. Previously, the patient underwent laryngeal tracheal reconstruction for subglottic stenosis and multiple subsequent revisions. During the diagnostic bronchoscopy, the left arytenoid was found to completely prolapse into the airway during inspiration requiring excision of the prolapsing tissue using the CO_2 laser. Oxygen was weaned to 21%, to facilitate laser fire safety conditions. During the initial ablation, the patient desaturated within 30 s to an SpO_2 of 48%. During this desaturation event, ST segment depression was noted on the EKG in leads 2 and 3. An endotracheal tube was placed by the ENT surgeon and the patient ventilated until resolution of the ST depression within 2 min. A Phillips iE33 (Cambridge, MA) ultrasound machine was immediately present and an anesthesiologist performed a point of care ultrasound examination. Ultrasound revealed normal ventricular function and absence of wall motion abnormalities. The ETT was removed and the surgeon attempted another ablation, during which time the patient desaturated to a low of 70% and the ST segment depressions returned. Continuous cardiac ultrasound demonstrated dyskinesia of the LV anterolateral wall and hypokinesia of the anterior and anteroseptal segments with preserved ejection fraction (Video 2). Due to the severity of the arytenoid prolapse and severe airway obstruction the procedure continued, however, based on the POCUS findings, the surgeon was requested to remove the remaining tissue with airway scissors allowing for 100% oxygen to be administered. The other planned non-urgent ophthalmologic surgical procedures were deferred.

Case 4

A 15-year-old, 61 kg female with Williams–Beuren syndrome presented for idiopathic posterior spinal fusion. Preoperative echocardiogram revealed moderate pulmonary valve stenosis with normally appearing coronary ostia and normal ventricular function. While gregarious, she was developmentally delayed, and therefore, premedicated with 15 mg oral midazolam. In the operating room, intravenous and arterial access were established with the aid of inhaled 70% N_2O/30% O_2 followed by pre-oxygenation to an end-tidal O_2 concentration of 90%. Baseline cardiac point of care ultrasound was performed by the anesthesiologist prior to induction to establish a baseline using the Sonosite (Fujifilm, Bothell, WA) using the 5–1 phased array probe. Induction was accomplished using fentanyl 5 mcg/kg over 15 min, 2 mg IV midazolam and propofol 100 mg without hemodynamic change. Direct laryngoscopy (DL) was performed resulting in immediate 3–4 beats of sinus bradycardia (62–28 bpm) followed by asystole resolving with cessation of the DL. An anesthesiologist performed ultrasound revealed a wall motion abnormality of the LV antero-septal wall which was not present on pre-induction TTE (Video 3). Phenylephrine, 250 mcg was administered in 50 mcg aliquots over 15 min. Thirty minutes following induction, hemodynamics remained stable and the LV appearance returned to baseline. The case was allowed to proceed and did so uneventfully.

Case 5

A 13-year-old patient with Pompe's disease and chronic respiratory failure requiring tracheostomy and mechanical ventilation presented for: replacement of portacath, examination of ears, and bronchoscopy. During an anesthetic 2 years prior, the anesthesiologist reported sudden onset of ST segment depression resolving with phenylephrine (however, no additional information recorded). Due to the potential for cardiac involvement in Pompe's disease, TTE 2 weeks prior to the surgery noted a moderate pericardial effusion with normal biventricular function. The patient was brought to the operating room and general anesthesia was induced. A 3 lead EKG was placed and examination of the ears was performed. The table was turned 90° for bronchoscopy, the patient draped and the procedure commenced. New onset of ST depression was noted on leads 2 and 3. Oxygen supplementation was given and the volatile agent concentration decreased. The initial decision was to defer the replacement of the portacath. As the ST segment depression persisted, an anesthesia POC ultrasound was performed. While a pericardial effusion was noted, there was no evidence of wall motion abnormality visualized in parasternal short or long axis view or apical 2 or 4 chamber view. Inspection of the EKG leads revealed that during rotation of the bed, the EKGs were reattached incorrectly. Lead correction resulted in normal appearing EKG and the case proceeded uneventfully.

Case 6

A 12-year-old female arrived for emergent drainage of a malignant left thoracic empyema. The patient was tachycardic (150 beats/min) with electrical alternans present on the EKG. Preoperative chest X-ray demonstrated subtotal opacification of the left lung in addition to a large 13 cm mass in the anterior right chest with left mainstem bronchial compression and rightward tracheal deviation. After a lengthy discussion with the patient and her mother, the anesthetic plan was to provide midazolam and assess her cardiac status using bedside ultrasound in the operating room. If severe compromise was present, the anesthetic plan would involve the use of local anesthetic and distraction techniques during the insertion of the pigtail chest drain. After entering the operating room and providing 2 mg intravenous midazolam, an anesthesiologist performed point of care cardiac ultrasound was performed revealing a massive left pleural effusion with pulmonary consolidation resulting in circumferential pericardial effusion and tamponade physiology (Fig. 1a, b). Reversal of flow was present in the intrahepatic inferior vena cava and hepatic veins (Figs. 2, 3). The exam also revealed paradoxical movement of the intra-atrial septum and collapse of the RA throughout the cardiac cycle and the RV during diastole highly predictive of tamponade physiology (Video 4). The case proceeded with verbal distraction by the anesthesiologist and generous local anesthetic administration in the field.

Discussion

Point of care ultrasound is an invaluable tool providing real-time assessment of cardiopulmonary function that is above and beyond the abilities of traditional physical examination [5–7]. At present, point of care ultrasound is recommended for utilization when a particular clinical question of interest arises [8]. Specifically, POCUS can help differentiate the causes of hemodynamic derangement as well as identify a pulmonary cause of instability [2]. Additionally, POCUS plays an important role during the intraoperative period to augment physical examination and even assist surgical management (e.g. case 1) [9]. Case 1 demonstrates a situation in which POCUS can be employed to aid the surgical procedural assessment. Traditional auscultation was not revealing due to harsh rhonchi; while use of a flexible bronchoscope was not tolerated in the setting of extreme

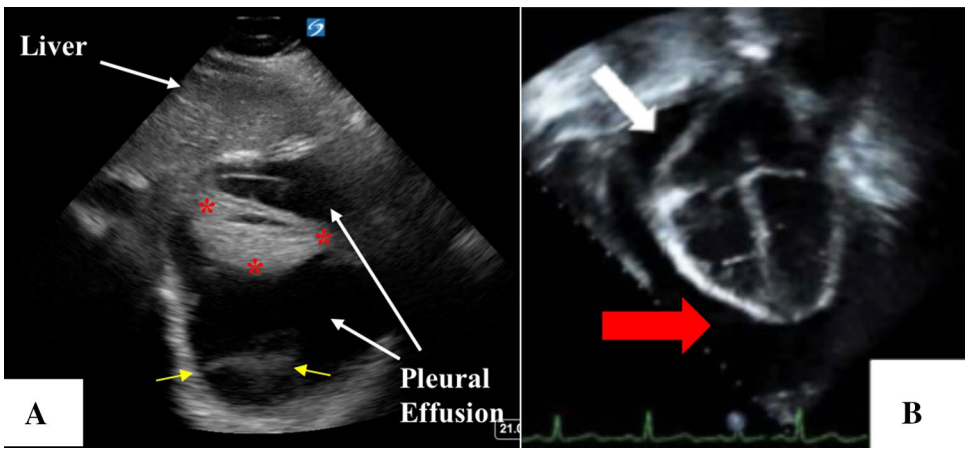

Fig. 1 Bedside ultrasound of the: **a** transverse IVC view revealing lung collapse (red stars) and large pleural effusion. Fibrinous exudate = yellow arrows and **b** apical 4-chamber view showing large circumferential pericardial effusion (red arrow) and collapse of the right atrium (white arrow)

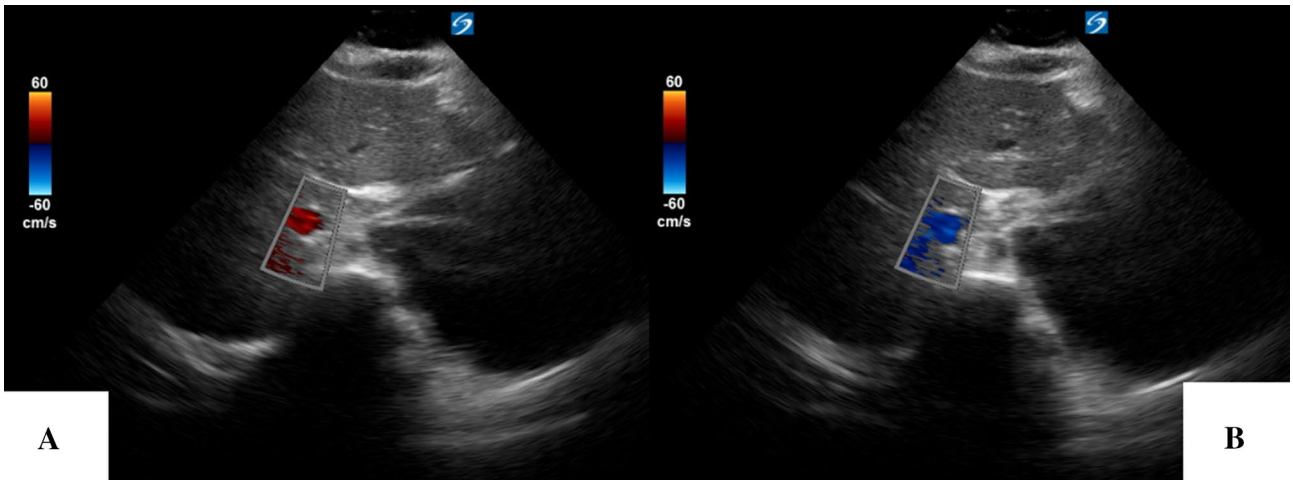

Fig. 2 Transverse IVC view with color flow doppler over the intrahepatic IVC. Without changing the probe position or orientation, the reversal of flow is indicated by change from red to blue

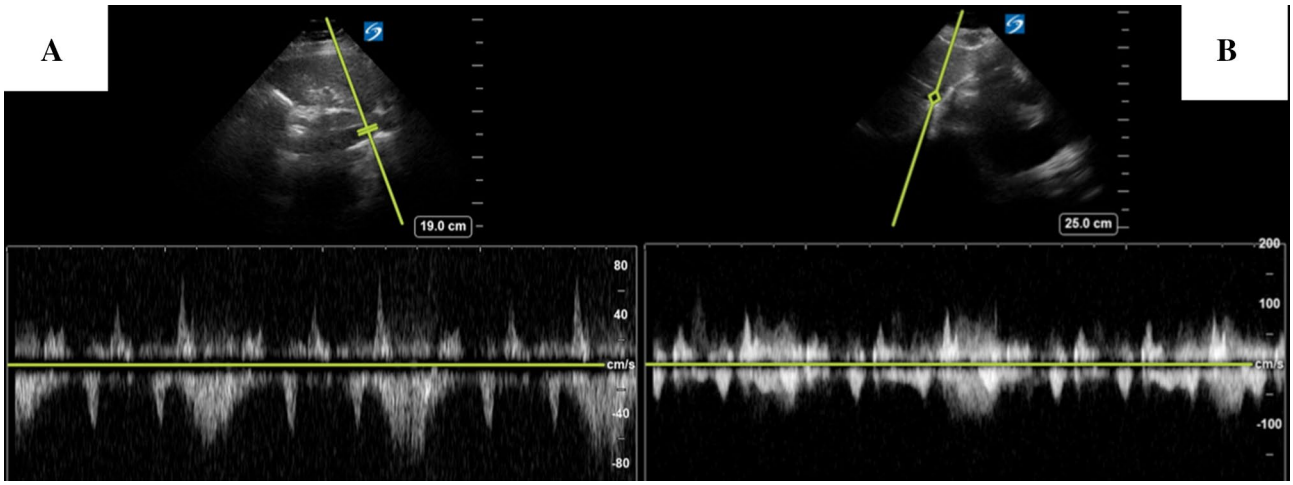

Fig. 3 Bedside ultrasound of the IVC long axis view with application of doppler at the junction of the IVC/right atrium (**a**) and the hepatic veins (**b**) demonstrating reversal of flow in both regions

ventilatory support. Similarly, in case 2, intraoperative ultrasound was performed in the midclavicular and midaxillary lines to assess lung segmental function. POCUS can be used to segmental isolation both prior to or after incision when other modalities are such as fluoroscopy are impractical. The presence of a lung pulse with absence of lung sliding indicates a segment with opposing visceral and parietal pleura (i.e. excluding pneumothorax) suggesting lung that is not being ventilated. Intraoperative lung ultrasound is an excellent perioperative tool to assess segmental lung function [1].

Cases 3–5 highlight the utility of intraoperative cardiac POCUS for informing clinical management. In case 3, ST segment depression and oxygen desaturation warranted intraoperative POCUS examination. The parasternal short axis view, while demonstrating regional wall motion abnormity also noted preserved overall ejection fraction (EF). While in most circumstances, these findings would prompt cancellation, the degree of critical airway obstruction necessitated completion. This decision was approached knowing the EF was preserved. However, given the wall motion abnormality in the setting of ST depression, the surgeon was requested to change to a non-cautery-based technique allowing oxygen administration and the unnecessary procedures were deferred. In case 4, POCUS, specifically the parasternal long and short axis views were being performed to establish a baseline in case the need for evaluation arose in the prone position for which transesophageal imaging would not be available. Patients with Williams–Beuren syndrome are known to have supravalvar and pulmonary artery stenosis with an incidence of 75% and 40% respectively [10].

Additionally, these patients are known to be at risk for intermittent coronary vasospasm and myocardial ischemia [11, 12]. In this case, intraoperative POCUS allowed for demonstration of both the new onset ventricular dyskinesia and its resolution. In situations of hemodynamic instability, POCUS may be used to evaluate intraoperative cardiac function. In case 5, given the known cardiac involvement in patients with Pompe disease coupled with a past history of prior ST segment depression during anesthesia, the development of new ST depression would merit deferment of elective procedures [13]. In this case, POCUS, and particularly the parasternal short axis view excluded any left ventricular wall motion abnormalities or large pericardial effusion avoiding unnecessary procedural cancelation. The utility of POCUS allows for confirmation of or exclusion of suggested ST depressions that are often erroneously detected when using a 3 lead EKG intraoperatively. Certainly, the use of ultrasound to augment traditional cardiac physical examination was beneficial in evaluating the electrocardiographic findings [14].

In case 6, intraoperative POCUS was used to determine the anesthetic performed in relation to severity of cardiopulmonary compromise. Initially, cardiac tamponade was suspected based on the EKG findings and underlying malignancy, however, once this was confirmed using POCUS, general anesthesia (which was preferred by the patient and family) was avoided. Ideally, for patient comfort, a general anesthetic would have been performed however, POCUS demonstrated significant cardiopulmonary derangement prompting reevaluation of the anesthetic plan. In cases of severe compromise, for select procedures, sedation and use of distraction techniques may be advantageous [15].

As with all technologies, there are significant limitations and POCUS in no exception. While POCUS may be employed for children with structurally normal hearts, cardiac ultrasound in patients with congenital heart disease should be referred to a pediatric cardiologist. POCUS relies on providers to learn basic image acquisition and recognize a series of ultrasonographic findings that represent a limited number of clinically relevant pathologies [16]. At present, POCUS does not involve quantitative measurements (e.g. ejection fraction, Doppler measurements, etc.) which falls in the scope of echocardiography. Use of measurements required additional training and experience as it may introduce the possibility of improper assessment by the novice sonographer. Finally, it is important to examine the heart in multiple views when possible. For example, identification of plethora of the inferior vena cava could signify euvolemia, however, it may be the result of another cardiac related finding (e.g. if found in the setting of a pericardial effusion or right heart failure).

This series demonstrates the utility of anesthesiology performed point of care ultrasound specifically augmenting intraoperative management based on real-time findings. Use of point of care ultrasound is a valuable perioperative tool providing cardiopulmonary assessment when other modalities are impractical or unavailable (e.g. TEE or fluoroscopy). In many intraoperative situations, the technical ease by which POCUS may be performed can prove difficult. However, in the majority of critical care situations, often a single view can identify major and hemodynamically significant pathologies [17]. Providers must acquire basic imaging skills and knowledge of image interpretation to perform high-quality and reliable POCUS for clinical care. Adler et al. have described the necessary pathway to achieve proficiency [2]. A 2017 survey of cardiac anesthesiologists (presumably more likely to adopt POCUS) reported minimal perioperative use [18]. While the anesthesia literature is plush with editorials on POCUS, the utilization remains sparse. This series highlights clinical situations in which the use of intraoperative POCUS is warranted and provides information beyond that of traditional examination. With the increasing complexity of patients and the relative frequency of cardiopulmonary related anesthetic issues, point of care ultrasound should be used as an excellent resource to augment clinical assessment and management.

Author contributions ACA: study design, data analysis, manuscript preparation and direct patient care. This author has approved the final manuscript. AC: study design and manuscript preparation. This author has approved the final manuscript. FTC: study design and manuscript preparation. This author has approved the final manuscript.

Funding None.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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