Integration of Point-of-care Ultrasound during Rapid Sequence Intubation in Trauma Resuscitation

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Abstract

Introduction: Airway and breathing management play critical role in trauma resuscitation. Early identification of esophageal intubation and detection of fatal events is critical. Authors studied the utility of integration of point-of-care ultrasound (POCUS) during different phases of rapid sequence intubation (RSI) in trauma resuscitation. **Methods:** It was prospective, randomized single-centered study conducted at the Emergency Department of a level one trauma center. Patients were divided into ultrasonography (USG) and clinical examination (CE) arm. The objectives were to study the utility of POCUS in endotracheal tube placement and confirmations and identification of potentially fatal conditions as tracheal injury, midline vessels, paratracheal hematoma, vocal cord pathology, pneumothorax, and others during RSI. Patient >1 year of age were included. Time taken for procedure, number of incorrect intubations, and pathologies detected were noted. The data were collected in Microsoft Excel spread sheets and analyzed using Stata (version 11.2, Stata Corp, Texas, U. S. A) software. **Results:** One hundred and six patients were recruited. The mean time for primary survey USG versus CE arm was (20 ± 10.01 vs. 18 ± 11.03) seconds. USG detected four pneumothorax, one tracheal injury, and one paratracheal hematoma. The mean procedure time USG versus CE arm was (37.3 ± 21.92 vs. 58 ± 32.04) seconds. Eight esophageal intubations were identified in USG arm by POCUS and two in CE arm by EtCO2 values. **Conclusion:** Integration of POCUS was useful in all three phases of RSI. It identified paratracheal hematoma, tracheal injury, and pneumothorax. It also identified esophageal intubation and confirmed main stem tracheal intubation in less time compared to five-point auscultation and capnography.

Keywords: Emergency department, point-of-care ultrasound, rapid sequence intubation

Introduction

Airway and breathing management play a critical role in trauma resuscitation in the emergency department (ED). Failure to secure the airway or detect breathing problems can lead to death or disability.[1] Rapid sequence intubation (RSI) is the method of choice and cornerstone of emergency airway management.[2-5] RSI has three phases: preoxygenation, endotracheal intubation, and tube confirmation.

Point-of-care ultrasound (POCUS) has emerged as the diagnostic standard of care in trauma and critical care settings. It plays a vital role in identifying breathing problems such as, hemothorax and pneumothorax during trauma resuscitation. Current systematic reviews have shown the benefits of POCUS in confirmation of correct endotracheal tube (ETT) placement with exclusion of esophageal intubation.[6,7] There are limited data on the utility of point-of-care sonography in RSI during trauma resuscitation.[8] Identifying conditions causing potentially fatal airway events such as occult pneumothorax, abnormal midline neck vessels, paratracheal hematoma, vocal cord pathology, and tracheal injury as a part of primary survey is critical during trauma resuscitation.

Authors studied the utility of POCUS in ETT placement, confirmation and time taken for tube confirmation. The authors also explored its role in identifying potentially fatal airway and breathing problems during the three phases of RSI within the defined time frame. Hence, we contemplated

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to study the integration of POCUS during RSI in trauma resuscitation.

Methods

It was prospective, randomized single-centered study conducted at the Emergency Department (ED) of a level one trauma center. The primary objective was to study the utility of POCUS in ETT placement and confirmations during RSI in trauma patients. The secondary objectives were (a) time taken for tube confirmation by POCUS, (b) identification of tracheal injury, midline vessels, paratracheal hematoma, vocal cord pathology, pneumothorax, and other potentially fatal conditions which may influence airway management.

Patient more than one year of age with indication for RSI was included. Age <1 year, patients in cardiac arrest on arrival in ED, overt tracheal injury, open thoracic wound, distorted neck anatomy, patients requiring surgical airway, and transfer-in patients from other centers with existing ETT in place were excluded.

The study consisted of two phases, namely, the training phase and execution phase.

Training phase

The training phase consisted of recruitment of senior resident doctors, nurses, and training them in protocols of RSI. The study team comprised of three members: a senior resident, a sonographer, and a time keeper.

Senior residents and nurses of ED who had adequate training and experience in POCUS were selected for the study. Each senior resident performed 20 intubations in airway manikin. They performed at least 20 supervised intubations before being recruited to the study. The observer (timekeeper) was a nurse informatics.

Team members were trained in execution of the study protocol by simulation on manikins. Ultrasound (US) clips were also utilized to enhance the simulation of US portion. The simulation session was supervised by the faculty emergency medicine who was not participating in the study. Ten simulation sessions were attended by each team member before the study.

Execution phase

Allocation of subjects: the study subjects were randomly assigned to clinical examination (CE) arm or US arm based on a computer-generated numerical randomization list. The sample size was 120. The treatment decisions, decision on airway management, utilizing any other radiological, or nonradiological investigation including ultrasonography (USG) was taken by the trauma team. All patients were resuscitated as per advance trauma life support (ATLS) guidelines. Demographic and relevant clinical details were recorded in predesigned format.

RSI was considered in three stages:
- Stage 1: Preoxygenation stage
- Stage 2: Tracheal intubation stage
- Stage 3: ETT confirmation stage.

The first stage of preoxygenation was of 3 min duration. The trauma team in both the arms (CE and US) performed a primary survey (CE) to identify airway and breathing problems as per the ATLS guidelines. The US arm also did the US of anterior neck and chest to look for tracheal injury, abnormal midline neck vessels, paratracheal hematoma, vocal cord pathology, and pneumothorax.

In the second stage, both the arms performed endotracheal intubation as per the standard protocol. The CE arm performed five-point chest auscultation combined with $EtCO_2$ to confirm the position of the ETT. In the US arm, the trained sonographer confirmed the position of the ETT in two steps: absence of esophageal intubation as step one and presence of left lung sliding as step two.

The time taken from the start of procedure (preoxygenation phase) to confirmation of ETT placement was recorded by the time keeper with an electronic stop watch with multiple laps. The number of esophageal and right main stem bronchus intubations and the time taken to detect and correct the same in both the arms was also recorded.

Ultrasound arm procedure

Phase I: Preoxygenation phase of rapid sequence intubation (3 min)

Step 1

The USG machine was switched on by the sonographer. Linear USG probe of 7–12 MHz frequency was placed longitudinally along the mid-clavicular line between 2nd and 4th intercostal space bilaterally. The presence of lung sliding ruled out pneumothorax [Figure 1].

Lung sliding

It is rhythmic to and fro movement of the pleural line with respiration during US scanning. When this movement was present, lung sliding sign was called positive. If absent, the lung sliding sign was called as negative. Lung sliding was further confirmed by the presence of 'sea-shore' sign [Figure 2] using M-mode of USG.[9]

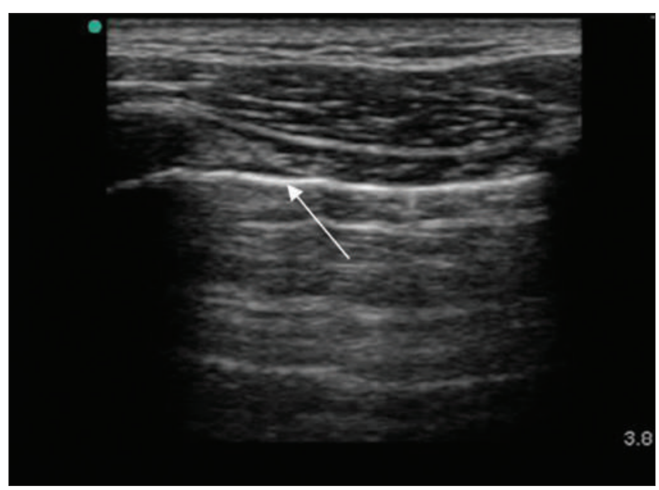

Figure 1: Pleural line on ultrasonography the arrow points to the white pleural line. When rhythmic to and fro movement of the line was seen with respiration, lung sliding was said to be present

Pneumothorax

Pneumothorax was diagnosed by the absence of lung sliding sign and by the presence of 'stratosphere sign' seen as horizontal lines below the pleural line [Figure 3] on M-mode.[10] If pneumothorax was present, further management was as per the ATLS protocol.

Step 2: Airway Survey

a. Longitudinal view: The probe was placed longitudinally on the anterior midline of neck to scan the trachea and evaluate for existing injury [Figure 4]. Tracheal injury on USG appeared as disruption of hyperechoic air mucosal line and hypoechoic tracheal cartilages [Figure 5].
b. Transverse view.
   (i.) Vocal cord level: The probe pointer was placed transversely in the middle of neck at the level of thyroid cartilage to survey the vocal cord movement and look for any existing vocal cord pathology [Figure 6]
   (ii.) Thyroid gland level: The probe was moved to the thyroid gland level which showed esophagus on the left side [Figure 7]. The right side of neck was scanned if the esophagus was not seen on the left side to check for anatomical variation. The presence of paratracheal hematoma was searched in this scan window. Abnormal midline vessels were also searched for as a part of preparation for surgical airway in case of failed intubation.

After the complete survey of airway and breathing, the findings were communicated to other team members during resuscitation and immediate intervention were done, if required.

Phase II: Tracheal intubation

During the actual procedure of intubation by the Emergency physician, the sonographer placed the probe transversely at the thyroid gland level to locate the esophagus. If the posterior wall (seen as a bright hyperechoic line) of esophagus was seen postintubation, it indicated tracheal intubation. If the tube entered the esophagus, it obscured the posterior wall of esophagus by the presence of a posterior dark acoustic

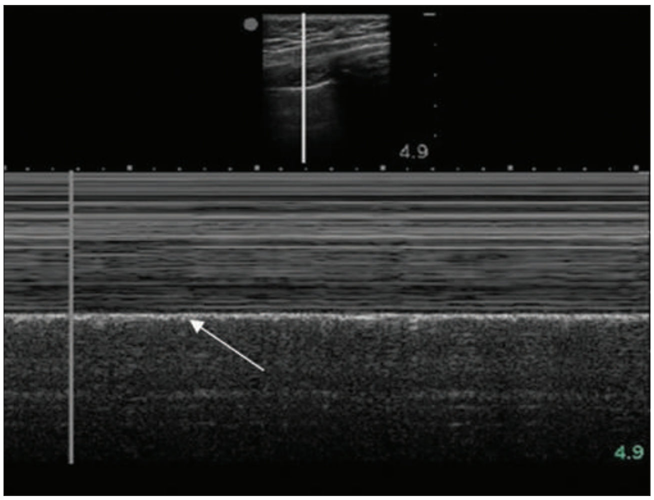

Figure 2: Seashore sign. The sign appears during M-mode (time-motion mode). The arrow points to the pleural line, the parallel lines correspond to the static thoracic wall and the sandy pattern under the pleural line is produced by the lung parenchyma. It is a dynamic artifact that disappears in pneumothorax (The parallel lines correspond to *sea*, the sandy pattern corresponds to *shore*, and their border corresponds to the pleural line, arrow)

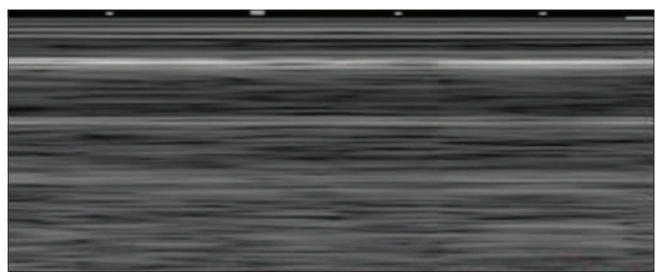

Figure 3: Stratosphere sign. The sign appears during M-mode (time-motion mode). This pattern of parallel lines resembling a "bar code" indicates a pneumothorax

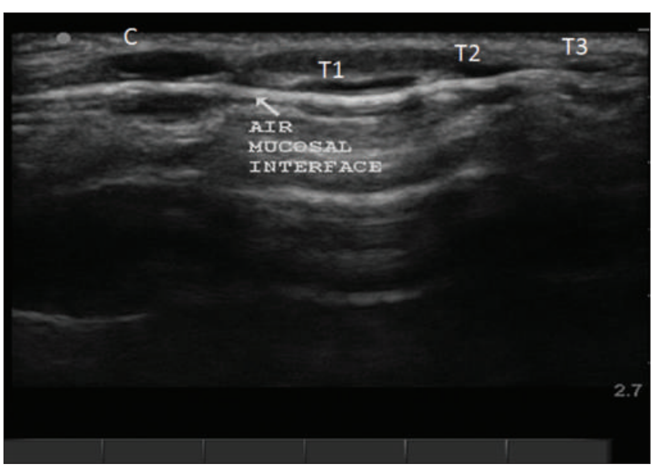

Figure 4: Normal longitudinal view of trachea and cartilages. The hyperechoic line represents the air-mucosal interface and cartilages are seen as hypoechoic rings. (C: Cricoid cartilage, T1, T2, T3: Tracheal rings)

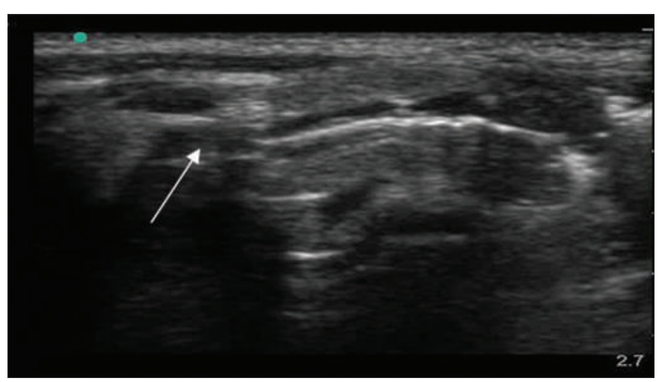

Figure 5: Tracheal disruption. The hyperechoic line representing the air-mucosal interface (arrow) and cartilages seen as hypoechoic rings are distorted suggesting tracheal injury (compare with Figure 4)

shadow [Figure 8]. When this occurred, the tube was removed immediately, and reintubation was attempted maintaining the oxygen saturation.

Phase-III: Confirmation of endotracheal tube placement

The probe was placed longitudinally on the midclavicular line between 2nd to 4th intercostal space on the left side of chest and the sonographer looked for lung sliding sign; if present, it confirmed correct tracheal intubation with tube placed centrally above carina and ruled out right main stem bronchus intubation. If lung sliding was absent on the left side, the probe was moved to the right midclavicular line. If the right lung sliding was present, it confirmed that it was a right main stem bronchus intubation. The tube was readjusted by withdrawing it till lung sliding sign was present on the left side.

Statistical analysis

The data were collected in Microsoft Excel Spread sheets and analyzed using Stata (version 11.2, Stata Corp, Texas, U. S. A) software.

Ethics approval

Ethics approval for the study was taken from the Institute ethics committee.

Results

One hundred and six consecutive patients were enrolled: 53 in USG arm and 53 in CE arm [Figure 9]. The male: female ratio was 5.6:1 in USG arm and 3.8:1 in CE arm. The details of age and gender have been shown in Table 1. Road traffic crash was the most common mechanism of injury seen in 24 in USG and 26 in CE arm [Table 2]. Airway protection was the most common indication for intubation for 50 in USG and 46 in CE arm. The mean time for primary survey was 20 s (standard deviation [SD] = 10.01) in USG and 18 s (SD = 11.03) in CE arm. Positive findings during the primary survey in both the arms are detailed in Table 3.

In the USG arm, a primary survey with the help of USG was also done during the preoxygenation phase of RSI. The median

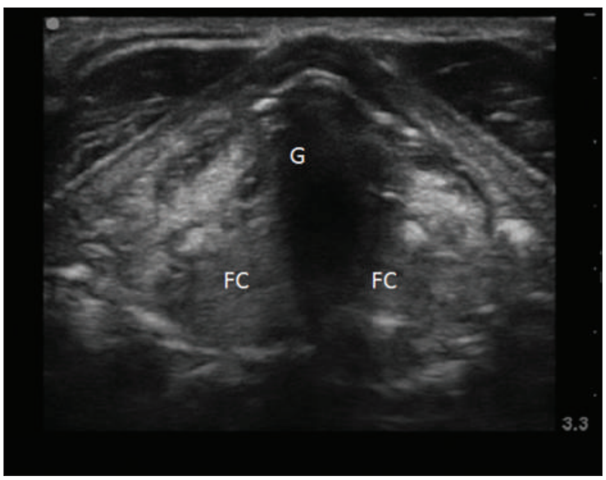

Figure 6: Transverse view of neck at the level of vocal cords. (G: Glottis, FC: False cord)

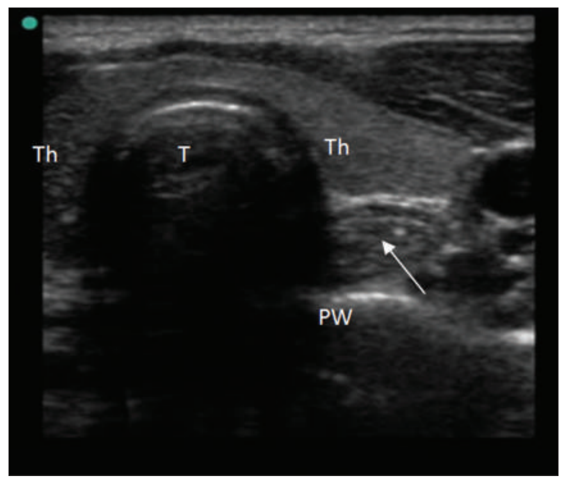

Figure 7: Transverse view of neck just above the suprasternal notch at the level of thyroid gland showing the Esophagus (arrow). (PW: Posterior wall of Esophagus, Th: Thyroid lobes, T: Trachea)

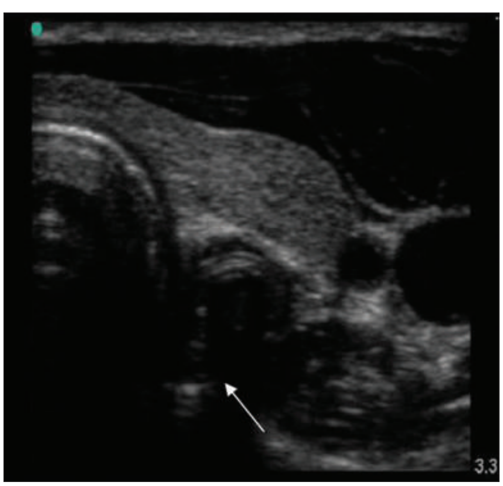

Figure 8: Transverse view of neck just above the suprasternal notch at the level of thyroid gland showing esophageal intubation. The posterior wall of esophagus is no longer visible-arrow (compare with Figure 7)

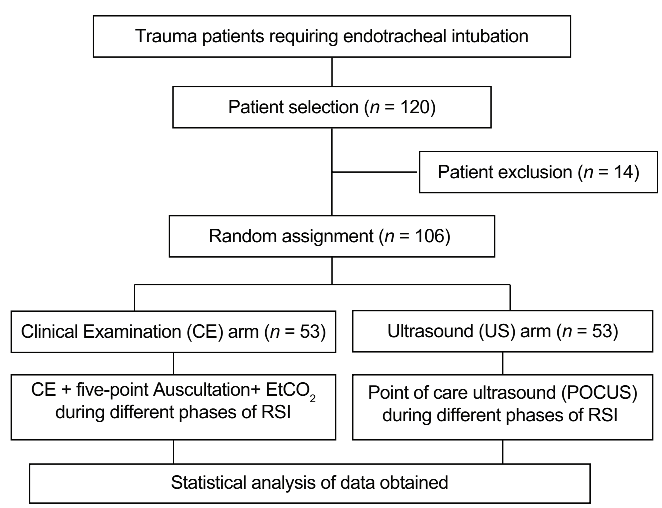

Figure 9: Flow chart of study protocol

time taken during this survey was 40 s (IQR = 30-55). The positive findings are detailed in Table 4 and Videos 1, 2.

The mean dynamic intubation time (i.e., the time from the start of intubation to exclusion of esophageal intubation) was 14.03 s (SD = 9.56) in the USG arm. The mean procedure time (i.e., from the start of intubation to correct tube placement confirmation by the left lung sliding sign) in the USG arm was 37.3 s (SD = 21.92). Similarly, the mean procedure time (i.e., from the start of intubation to correct tube placement confirmation by EtCO2 value) was 58 s (SD = 32.04) in the CE arm. Eight esophageal intubations were detected by POCUS and the mean time taken to detect them was 18.25 s. The mean reintubation time taken was 23.12 s for these cases where correct tube placement was confirmed by the left lung sliding sign. Two esophageal intubations were noted in the CE arm, which were diagnosed by EtCO2 values and the mean time taken to detect them was 177.5 s. The mean reintubation time was 39.5 s for these cases where correct tube placement was again confirmed by EtCO2 value. Two right mainstem bronchus intubations were noted in the USG arm by looking at the left lung sliding sign but no right mainstem bronchus intubations were noted in the CE arm.

Table 1: Age and sex distribution of patients in ultrasound and clinical examination arm

	USG arm (*n*=53)	CE arm (*n*=53)
Median age in years (IQR)	30 (18-43)	25 (16-37)
Male	45	42
Female	8	11

USG: Ultrasound, CE: Clinical examination, IQR: Interquartile range

Table 2: Mechanism of injury in ultrasound and clinical examination arm patients

	USG arm (*n*=53)	CE arm (*n*=53)
RTC	24	26
Assault	22	21
Fall from height	2	1
Others*	5	5

*Drowning, electrocution, hanging, railway track injury, etc.,
USG: Ultrasound, CE: Clinical examination, RTC: Road traffic crash

Table 3: Findings in primary survey (without ultrasound)

	USG arm (*n*=53)	CE arm (*n*=53)
Visible airway injury	2	1
Clinical pneumothorax	2	1
Maxillo-facial injuries	4	2

USG: Ultrasound, CE: Clinical examination

Table 4: Findings in ultrasound guided primary survey (*n*=53)

	n
Absent lung sliding	4
Tracheal injury	1
Paratracheal hematoma	1

Discussion

Conventionally, five-point auscultation has been considered the method of choice for exclusion of esophageal intubation. This procedure takes time, has high chances of aspiration of gastric contents with each ambubag insufflation, and is unreliable in noisy environments. EtCO2 values are considered the gold standard for confirmation of correct ETT placement. However, again, these values are sometimes erroneous and unreliable, the probes are costly and not available at all the centers, and the device needs some time before the values are reflected on the monitors. Delay in confirmation of ETT during RSI is often fatal. POCUS is emerging as the modality of choice for same.[11]

Esophageal intubations were detected by USG arm in 18.25 s vs 177.5 s in CE arm. Dynamic POCUS identified wrong intubations early when compared to the conventional method. The mean procedure time (i.e., from the start of intubation to correct tube placement confirmation by presence of the left lung sliding sign in the USG arm and by EtCO2 value in the CE arm) was less in the USG compared to the CE arm (37.3 vs 58 s). The difference again reflects the time saved during RSI in airway management. Systemic review and meta-analysis have demonstrated high diagnostic value of USG in identifying esophageal intubation.[6] Blaivas and Tsung used sonographic detection of the sliding lung sign, the lung pulse, and diaphragmatic excursion to detect main-stem bronchial intubation.[12] We used absence of esophageal intubation and presence of the left lung sliding sign as a marker of main stem bronchus intubation. The absence of esophageal intubation and absence of the left side lung sliding sign was used as a marker of right main-stem bronchus intubation. Correction was done by withdrawing ETT till the lung sliding appeared equally on both lung zones.

Literature supports the superiority of USG over five-point auscultation and EtCO2 in adult and pediatric patients. Chou *et al*. compared the concordance between the tracheal rapid US examination (TRUE) and capnography in confirmation of tracheal intubation in emergency.[13] 112 patients were included in the analysis, and 17 (15.2%) had esophageal intubations. The overall accuracy of the TRUE was 98.2% (95% confidence interval [CI]: 93.7–-99.5%). The kappa value was 0.93 (95% CI: 0.84–1.00), indicating a high degree of agreement between the TRUE and capnography. The sensitivity, specificity, positive predictive value, and negative predictive value of the TRUE were 98.9% (95% CI: 94.3%–99.8%), 94.1% (95% CI: 73.0%–99.0%), 98.9% (95% CI: 94.3%–99.8%), and 94.1% (95% CI: 73.0%–99.0%). The median operating time of the TRUE was 9.0 s (interquartile range [IQR]: 6.0–14.0).

We used lung sonography as an adjunct to rule out esophageal intubation for ETT confirmation. Chun *et al*. studied thoracic USG to confirm ETT placement.[14] They used a portable, hand-held, US machine. Sonographic recordings of the chest wall visceral-parietal pleural interface were recorded bilaterally in each patient during all phases of airway management. This technique may have merit in extreme environments, such as in remote, prehospital settings or during aerospace, medical transports, in which auscultation is impossible due to noise, or capnography is not available, and thus, requires further scientific evaluation.

Marciniak *et al*. evaluated the usefulness of US in confirming endotracheal intubation in pediatric patients.[15] They used US while endotracheal intubation and further confirmed with chest auscultation and EtCO2. Successful tracheal intubation was verified using the following criteria: (1) Identification of the trachea and tracheal rings, (2) visualization of vocal cords, (3) widening of glottis as the tracheal tube passes through, and (4) tracheal tube position above carina and demonstration of lung sliding sign. We used two steps rather than four steps for ETT confirmation as per our study protocol which was less time-consuming.

In the present study, emergency physicians intubated the patient, and US guidance was provided by a trained emergency nurse or another emergency physician. Bunymin Muslu studied 150 patients in which the anesthesiologist randomly placed ETT either in the trachea or in the esophagus. The sonographer was an anesthesiologist with adequate training.[16]

These observations reflect that POCUS can be done even by nonradiologists after proper training and they can be utilized, especially during disasters when resources and hands are limited.

The present study algorithm identified airway injury (two in USG and one in CE arm), pneumothorax (two in USG and one in CE arm), and maxillofacial injuries (four in USG and two in CE arm) during the primary survey. The primary survey was done during the 3 min preoxygenation phase of RSI. Apart from this, POCUS was able to detect absent lung sliding (i.e., Pneumothorax) in four, tracheal injury in one, and paratracheal hematoma in one patient during the USG-guided primary survey. This USG-guided primary survey was done within the defined time frame of RSI. Hence, it identified additional pathologies which were missed clinically. Earlier studies have also shown the superior utility of US in detecting isolated cases of pneumothorax.[17,18] The integration of POCUS in identifying occult pneumothorax, abnormal midline neck vessels, paratracheal hematoma, vocal cord paralysis, and tracheal injury as a part of the primary survey during preoxygenation phase of RSI were not done in the previous studies.

Limitation

The sample size was small to identify the potentially fatal conditions which can impact airway management. Further large studies may explore the integration of POCUS with RSI during resuscitation of trauma patients. Future research may address the role of nurses as sonographers during RSI in acute care.

Conclusion

Integration of POCUS was useful in all the three phases of RSI. It identified paratracheal hematoma, tracheal injury, and pneumothorax during preoxygenation within the defined time frame of RSI. It also identified esophageal intubation and confirmed main-stem tracheal intubation in relatively less time compared to five-point auscultation and capnography.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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