ORIGINAL ARTICLE

Correlation of Ultrasound Examination with FOB for Airway Assessment in Burn Patients with Inhalational Injury: A Prospective Observational Study

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Abstract

Aim/background: Fiberoptic bronchoscopy (FOB) is the gold standard for assessing airway involvement in burn patients but is invasive. Ultrasound (USG) has not been previously used to evaluate the airway in burn patients. Our study evaluated the feasibility of using USG to assess airway involvement in inhalational burn injury and correlated its efficacy with FOB.

Materials and methods: This prospective observational study was conducted in the burns intensive care unit (ICU) of a tertiary care hospital. Bedside airway USG was performed to evaluate vocal cord (VC) width for edema and other airway parameters, including tongue thickness, pre-epiglottis space depth, inter-arytenoid distance, epiglottis-to-midpoint of VC, distance between the true VCs, distance between the false VCs, tracheal wall thickness, and tracheal air column width. Fiberoptic bronchoscopy was then performed to assess airway involvement, and findings were correlated with USG at the VC level.

Results: About 51 patients were included. Airway USG assessment was able to predict the VC edema, correlating with FOB findings in 30 patients. Ultrasound showed a sensitivity and specificity of 85.2 and 81.3%, respectively, with a positive and negative predictive value of 90.9 and 72.2%, respectively, for assessing airway edema at the level of VC. The mean right and left VC widths were 21.15 $\pm$ 9.52 mm and 22.03 $\pm$ 9.52 mm, respectively, in patients with VC edema. The pre-epiglottis space in patients with ($n = 33$) vs without VC edema ($n = 18$) was found to be statistically significant (14.5$\pm$ 5.64 mm vs 10.87 $\pm$ 4.36 mm; $p = 0.02$).

Conclusion: Ultrasound can be used as a reliable, non-invasive bedside predictor of airway involvement in patients with suspected inhalational injury.

Keywords: Airway assessment, Bedside ultrasound, Burns, Fiberoptic bronchoscopy, Vocal cords.

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Highlights

- Airway assessment in patients with inhalational burn injury using ultrasound reliably correlates with the gold standard of fiberoptic bronchoscopy (FOB), with 85.2% sensitivity and a 90.9% positive predictive value.
- Vocal cord (VC) edema is a predictor of a difficult airway in patients with inhalational burns.
- In patients with inhalational injury, pre-epiglottis space is significantly increased.

Introduction

Inhalational injuries are the fourth most frequent result of trauma worldwide and one of the most important predictors of mortality.[1,2] The inhalational injury affects the respiratory system by damaging the airways, which manifests as erythema, ulceration, and edema.[2] Symptoms such as dyspnea, hoarse voice, and stridor may not be apparent until swelling of the tongue, glottis, and epiglottis becomes severe enough to obstruct the upper airway, which could be potentially life-threatening.[3]

A retrospective analysis found that the presence of soot in facial burns warrants FOB, as these patients are at a higher risk of developing laryngeal edema.[4] It has been reiterated in many studies that FOB evaluation of airway should be incorporated in routine practice for patients with inhalational burns.[5] However, it is an invasive technique that requires complex equipment, sedation, and expertise.[6]

Recent years have witnessed an increased use of ultrasound (USG) in the evaluation of the upper and lower airway to assess any evidence of trauma, the presence of edema, confirmation of intubation, and VC dysfunction.[6,7] Both true and false VCs can be quantitatively measured with good reliability and reproducibility

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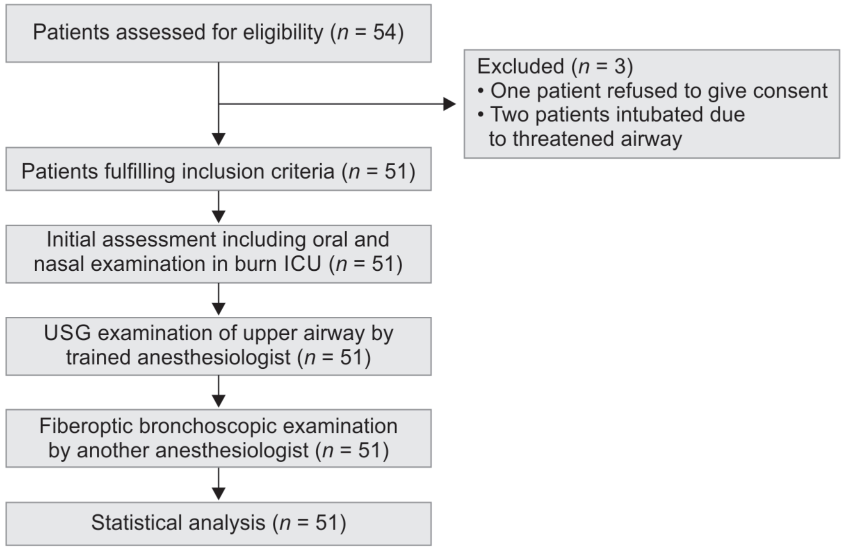

Fig. 1: CONSORT diagram

using USG, which may prove to be an alternative non-invasive choice for clinical and research applications.[8] It is a readily available bedside non-invasive technique to visualize airway dimensions and possibly predict difficult airway.[9] Ultrasound has not been used previously to evaluate the airway in burn patients, and no quantitative measurements of airway parameters in burn patients are available. This study was done to assess the feasibility of airway assessment at the level of VCs using USG in patients with inhalational injury and to correlate with the FOB findings. The secondary objectives were to assess airway parameters, including tongue thickness (TT), pre-epiglottis space depth (PES), inter-arytenoid distance (IAD), epiglottis-to-midpoint of vocal cords (EVCs), right and left VC width, distance between the right and left VCs, distance between the false VCs, tracheal wall thickness, and tracheal air column width (ACW).

Materials and Methods

This single-center, prospective, correlational observational trial was conducted in the Burns intensive care unit (ICU) of a tertiary care hospital. The study was performed after ethics committee approval and trial registration (CTRI/2022/10/046859). Written informed consent was obtained as per the Declaration of Helsinki (1964). Patients above 18 years of age with American Society of Anesthesiologists (ASA) physical status I or II who presented to burns emergency department with inhalational or suspected inhalational airway injury requiring ICU admission were included in the study from October 2022 to October 2023. Patients who refused to give consent, requiring urgent intubation in view of threatened airway and had airway or maxillofacial trauma were excluded.

Demographic data, including age, sex, weight, height, body mass index (BMI), comorbidities, mode of inhalational injury, and baseline hemodynamic parameters, including heart rate (HR), saturation (SpO_2), systolic blood pressure (SBP), and diastolic blood pressure (DBP), were recorded.

At initial presentation in the ICU, the oral and nasal cavities were assessed for the presence of soot particles, mucosal ulcerations, singed nasal hair, and any signs of airway obstruction, such as dyspnea, hoarseness, stridor, or oxygen requirement to maintain saturation.

A bedside USG scan of the airway was performed by a single anesthesiologist to reduce the risk of bias, in a supine position with slight head extension using a high-frequency linear transducer of 5–12 MHz (Sonosite EDGE™) for all patients. The anesthesiologist had an experience of more than 3 years in performing airway USG with structured training. Vocal cords being the narrowest part of the adult upper airway, inhalational burn injury results in edema, causing acute obstruction and stridor.[10] So, VC width was taken as a parameter to correlate with the grading of FOB. For assessing airway edema, a VC width of ≥10 mm and fullness of the false VC in the arytenoids was taken as a marker of edema using the USG (Fig. 1). The reference standard for VC edema was taken from the study by Hu et al., who showed that sonography is a reliable and reproducible method for measuring true and false VC, giving standard measurements and a preliminary study by Bright et al. which found average VC size of 7.5 mm ± 3.2 mm.[8,9] A case report by Schick and Grether-Jones found significant asymmetry at the level of the false VCs, indicating fullness in the arytenoids and published promising evidence on the use of airway ultrasound in emergency settings to identify airway edema.[11] A VC width of ≥10 mm was considered positive for edema on USG examination. Transverse and longitudinal scans were done from the submandibular region to the tracheal rings in a sequential manner, with specific focus on the region above and below the thyroid cartilage. The transducer was moved superiorly and inferiorly in the transverse plane until the VCs were clearly identified through patient phonation. The depth of PES, EVC, width of right and left VC, distance between the true VCs, distance between the false VCs, IAD, ACW, and tracheal wall thickness were measured in the transverse scan using the caliper method. The TT was measured in the longitudinal scan using USG.[12]

Subsequently, another anesthesiologist, blinded to the USG findings, conducted the airway examination and performed FOB (Ambu® aScope™) using airway preparation and sedation as per the institute's protocol. The fiber-optic grading was done according to the FOB classification of inhalation injury: Prediction of acute lung injury from grade 0 to 3, defined as G0 – negative; G1 – mild

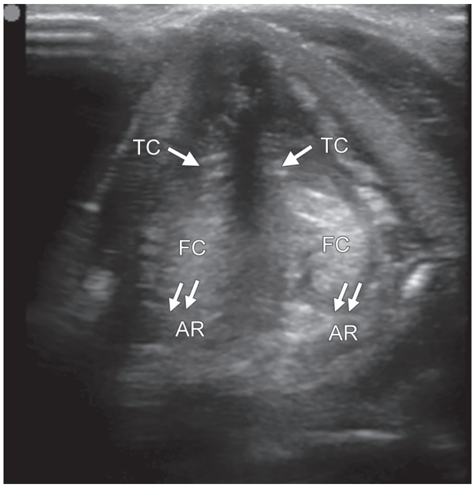

Fig. 2: USG showing true vocal cords (TC), false vocal cords (FC), fullness into the arytenoids (AR)

mucosal edema and hyperemia, with or without carbon soot; G2 – severe mucosal edema and reddening, with or without carbon soot; G3 – ulcerations, necrosis, and absence of both cough reflex and bronchial secretion.[13] An FOB grade ≥1 was considered abnormal on FOB examination.

The MS Excel® and SPSS® 10.5 (SPSS Inc., Chicago, IL, USA) software packages were used for data entry and analysis. There are no similar previous studies found in the literature. For a continuous outcome, a sample size of anywhere from 12 per group to 35 per group has been proposed.[14] The larger the sample size for the pilot, the greater the precision in estimating the results. For this novel study, a target sample size of 50 participants was selected based on pragmatic considerations of feasibility of recruitment and likely to provide potential outcomes.[15] Demographic data, baseline hemodynamic parameters, and airway examination parameters were tabulated and presented as mean ± standard deviation (SD) for continuous data. The predictive value of the tests was assessed by calculating sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and prevalence.[15] The level of significance was set at 5% (p at 0.05). All p-values less than 0.05 were considered significant.

Results

In this preliminary study, a total of 54 patients were enrolled. One patient refused to give consent, and two patients were intubated in the emergency department due to a threatened airway. Finally, 51 patients (19 females, 32 males) were involved in the final analysis (Fig. 2). The demographic and baseline hemodynamic data are presented as mean ± SD (Table 1). Initial airway examination, including oral cavity, nasal cavity, obstruction, and O_2 requirement, showed a high index suspicion of inhalational injury (Table 2). The mean duration between the time of burn and airway assessment was 20.21 ± 8.23 hours. Fiberoptic bronchoscopy revealed a grade I or higher in 35 patients (Table 3). No patients with FOB grade III were included as patients with extensive airway involvement were immediately intubated upon presentation. Ultrasound assessment was able to predict the airway edema, correlating with FOB findings in 30 patients (i.e., VC width ≥10 mm). The different parameters of upper airway examination on USG are presented as mean ± SD with p-values (Table 4).

Table 1: Demographic profile and baseline hemodynamic parameters

Parameter	*Mean ± SD*
Age (years)	34.03 ± 12.09
Height (cm)	170.08 ± 8.07
Weight (kg)	65.37 ± 10.44
BMI (kg/m^2)	22.58 ± 3.22
HR (beats/min)	98.57 ± 18.59
SBP (mm Hg)	135.14 ± 18.09
DBP (mm Hg)	79.44 ± 9.98
SpO_2 (%)	98.39 ± 1.47

BMI, body mass index; DBP, diastolic blood pressure; HR, heart rate; SBP, systolic blood pressure; SpO_2, saturation

Table 2: Airway assessment for smoke inhalational injury

Parameters		*Present [n (%)]*
1.	Oral cavity	
	Soot	9 (17.65)
	Redness/ulceration/swelling	21 (41.17)
	None	23 (45.09)
2.	Nasal cavity	
	Singing	43 (84.32)
	None	8 (15.68)
3.	Upper airway obstruction	
	Hoarseness of voice	13 (25.49)
	None	38 (74.51)
4.	Requirement of oxygen	
	Yes	27 (52.94)
	No	24 (47.06)

All the patients included in study had high suspicion of inhalational injury

Table 3: Correlation of FOB and USG finding

	VC edema on USG		
FOB grade	*Positive*	*Negative*	*Total*
Positive (≥1)	30	5	35
Negative (0)	3	13	16
Total	33	18	51

FOB, fiberoptic bronchoscopy; USG, ultrasound, positive for edema on USG: VC width ≥ 10 mm, negative for edema on USG: VC width < 10 mm, positive for edema on FOB: grade ≥1; negative on FOB: Grade 0

The mean right and left VC width was 21.15 ± 9.52 mm and 22.03 ± 9.97 mm, respectively, in patient with positive findings on USG assessment (p = 0.00). The mean distance between the VCs was measured in patients with or without VC edema on USG assessment (3.23 ± 1.71 mm vs 3.94 ± 2.05 mm; p = 0.19). The overall ability of USG to predict the presence of airway edema showed a sensitivity and specificity of 85.2% (confidence interval (CI): 69.7–95.2%) and 81.3% (CI: 54.4–96%), respectively, with a PPV and NPV of 90.9% (CI: 75.7–98.1%) and 72.2% (CI: 46.5–90.3%), respectively (Table 3).

The distance between the false VCs was measured as 7.96 ± 2.67 mm and 9.17 ± 2.24 mm in groups with and without VC edema, respectively (p = 0.11), but this was statistically insignificant.

Table 4: Ultrasound assessment of airway parameters

USG parameter (mm)	*Mean ± SD (mm), n = 33 (with VC edema)*	*Mean ± SD (mm), n = 18 (without VC edema)*	*p value*
Tongue thickness	44.30 ± 12.94	45.83 ± 10.72	0.67
Pre-epiglottis space depth	14.5 ± 5.64	10.87 ± 4.36	0.02*
Epiglottis-to-midpoint of VC distance	16.68 ± 5.85	13.82 ± 4.21	0.07
Right VC thickness	21.15 ± 9.52	9.11 ± 4.26	0.00*
Left VC thickness	22.03 ± 9.52	8.72 ± 3.65	0.00*
Distance between true VC	3.23 ± 1.71	3.94 ± 2.05	0.19
Distance false VC	7.96 ± 2.67	9.17 ± 2.24	0.11
Inter-arytenoid distance	6.50 ± 2.45	7.42 ± 2.56	0.22
Tracheal wall thickness	2.90 ± 2.97	2.20 ± 1.17	0.35
Air column width	13.10 ± 3.97	15.06 ± 3.91	0.57

With VC edema group: VC width ≥10 mm; without VC edema group: VC width <10 mm; *Significant *p*-value

Pre-epiglottis space depth measured in patients with VC edema vs those without VC edema was found to be statistically significant (14.5 ± 5.64 mm vs 10.87 ± 4.36 mm; $p = 0.02$). Epiglottis-to-midpoint of vocal cord was found to be more in patients with VC edema than in the other group, but the data was not statistically significant (16.68 ± 5.64 mm vs 10.87 ± 4.36 mm; $p = 0.07$). The mean IAD measured in patients with VC edema was 6.50 ± 2.45 mm, while in patients without edema, it was 7.42 ± 2.56 mm ($p = 0.22$). On tracheal examination, ACW and tracheal wall thickness were calculated as mean ± SD in patients with vs without VC edema (13.10 ± 3.91 mm vs 15.06 ± 3.91 mm; $p = 0.57$ and 2.90 ± 2.97 mm vs 2.20 ± 1.17 mm; $p = 0.35$), respectively (Table 4).

Discussion

This is a novel study evaluating and measuring airway involvement using USG in patients with inhalational injury in the burns ICU, correlating the findings with FOB. The use of high-frequency linear ultrasound in this study has provided both subjective and objective parameters of airway edema due to inhalational injury and can be a potential screening tool to help in early institution of measures of airway management obviating the need for sedation and complex invasive procedure like FOB in all patients. The effect of inhalation burn injury causes a progressive mucosal hyperemia and plasma transudation, which can cause a gradual decline in the VC lumen.[16] Collectively, these insults potentiate airway narrowing, resulting in obstruction. Prompt examination, diagnosis, and multimodal treatment improve outcomes.

Performing bronchoscopy to examine the airway is indeed a complex procedure in terms of patient preparation to tolerate the procedure and performing the procedure. A simple and rapid airway examination is possible using USG which helps in serial assessment of respiratory parameters to know the progression of airway edema. Our study has shown that increased width of the VC was able to reliably predict the presence of airway edema found on FOB in 85.7% patients with 90.9% PPV. A high PPV describe the performance of a diagnostic test and interpreted as indicating the accuracy of statistical analysis.[17] Vocal cord are the narrowest part of adult upper airway, and inhalational burn injury can result in edema, causing acute obstruction and stridor.[10] Also, larynx is positioned in direct exposure of inhalational burns and VC being the narrowest part, leading to increased chance of abnormal laryngeal findings in patients with burns causing significant morbidity in terms of difficult airway.[18]

Ultrasound reliably identifies the true and false VCs at the level of the thyroid cartilage in a transverse scan by sliding the transducer in a cephalon-caudad direction over the thyroid cartilage in all patients. The true VCs delineated medially as two paired, triangular hypoechoic structures, while the false VCs lie parallel and cephalad to the true cords, appearing more hyperechoic and relatively immobile during phonation.[8] Laryngeal lumen narrowing caused by edema or VC dysfunction leads to an increase in airflow velocity, manifesting as stridor, which is a clinically significant sign of impending airway obstruction.[19] Also, VC edema results in decreased VC mobility (adducted positioning of cords), thereby increasing the work of breathing and increased risk of aspiration which surges the risk of respiratory failure in patients with inhalational burns. It is assumed that stridor and respiratory distress occur when more than half of the luminal area is obstructed.[19] We found a reduced distance between the VC in patients with VC edema in our study, though the results were statistically insignificant. Studies with a higher sample size are needed to validate the findings.

Schick and Grether-Jones published promising evidence on the use of airway USG in emergency settings to identify false VC fullness and impending threats to the airway.[11] A case report by Wong and Chen, emphasized on use of transcutaneous laryngeal USG as an adjunct to evaluate the intra–false VC lesions and showed that USG is easily available and can quickly and serially providing real time imaging of false VC swelling.[20] In our study, we measured distance between the false VC to determine the airway oedema using USG and showed that the distance between the false cords was reduced in patients with VC oedema than the other group. However, the results were statistically insignificant.

Inhalational injury affects the upper airway, causing significant airway edema, leading to obstruction. Therefore, we measured airway parameters that contribute to obstruction, intubation difficulty, and respiratory failure in critical care settings. Ultrasound was reliable to evaluate these upper airway parameters in our study. We found a higher TT in the group with VC edema compared to the other group, though the results were statistically insignificant, necessitating a more powered study with larger sample size. The burn patients are aggressively administered crystalloids for initial resuscitation, which can reduce the plasma oncotic pressure and the local inflammatory response increasing capillary permeability leading to more significant increase in upper airway edema and further increase in airway obstruction.[21,22] Serial USG will be helpful in determining these changes associated with ongoing resuscitation and assess if TT changes over time with fluid resuscitation. An increased TT of >60 mm on USG assessment in the mid-sagittal plane is found to be an independent marker of difficult intubation in adult patients.[23] During laryngoscopy, the tongue is displaced into the submandibular space to visualize the glottis. Therefore, an increased TT can lead to difficulty during laryngoscopy and impair the glottic view.[24] Hall et al. found good inter-operator reliability in measuring upper airway parameters using USG in emergency to predict difficult airways and found that TT at base and tongue base-to-skin thickness increases with increasing Mallampati score, indicating a correlation between TT and difficult intubation.[25,26]

A larger PES, as well as smaller EVC distance, have a correlation with difficult airway instrumentation, including laryngoscopy and intubation, in terms Cormack–Lehane (C–L) grading, as greater force is required to lift the large epiglottis, which is reflected by a deep PES.[27] In our study, we found a significantly larger PES depth in the VC edema group than in the other, suggesting a difficult airway. We observed a reduced IAD in the group with VC edema compared to the other group, but statistically inconsequential in our study. Inter-arytenoid distance is important as it marks the space where any foreign body, whether accidentally inhaled or iatrogenically introduced, occupies and brushes by the side of the vocal process as it marks the smallest distance in the posterior part of the subglottis and IAD also guides the endotracheal tubes size during intubation.[28] Therefore, a reduction in IAD may contribute to a potentially difficult airway in burn patients as well.

In a recent case report, Kameda and Fujita identified airway edema as hypoechoic thickening of the tracheal wall on airway USG in a patient with inhalational burns and mentioned the usefulness of tracheal USG to predict edema and progression of edema, and it has the advantage of being easily accessible to patients, with the possibility of serial studies and providing real-time findings.[29] Our study showed a slightly thickened tracheal wall with reduced ACW in the VC edema group compared to the other group but statistically insignificant. However, these findings are clinically important, as inhalational burn injury can lead to progressive tracheal wall edema.

This is a preliminary study which paves the way for using USG in the assessment of airway involvement in patients with suspected inhalational injury and diagnosing difficult airway. Although various airway parameters were assessed to find out which airway parameter can be significantly useful to correlate with airway edema using USG examination. The initial assessment in the ICU was done at mean duration of 20.21 $\pm$ 8.23 hours after the episode of burns. The USG examination of airway showed that the primary outcome, i.e., increased thickness of right and left VC was found to be statistically significant for airway edema. Out of all the other parameters, only the depth of PES was significantly correlated. The practical implication of this study is the potential to correlate VC thickness as a solitary parameter to assess airway edema in patients presenting with inhalational injury who potentially needs airway protection using USG which is quick, portable, non-invasive, radiation free, with good reproducibility and reliability.

There are a few inherent limitations to this study. The first being the small sample size of the study. A larger sample size may show statistically significant results for other airway parameters. Another limitation is that ultrasound is not feasible for immediate use in a threatened airway. Our study showed good sensitivity but lower specificity, which indicates USG as a screening test rather than diagnostic test. Single anesthesiologist was involved to perform airway USG to the patient to reduce the bias but it might affect the generalization of results. Lastly, the inability of the USG to assess the severity and grading of the airway burn injury due to lack of available literature necessitates further studies.

Conclusion

Focused airway USG may be used as a reliable, non-invasive, bedside predictor of airway edema in burn patients with suspected inhalational injury. Further studies are needed to determine whether USG is sufficiently sensitive and specific for identifying airway edema and validating our findings.

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Authors' Contribution

Conceptualization, methodology, investigation, formal analysis, writing original draft preparation: HG. Data curation, writing – original draft preparation: SA. Methodology, investigation, writing – review and editing: AK. Conceptualization, validation, data curation, writing – review and editing: SK. Conceptualization, supervision, investigation: VD. Resources, project administration, supervision: LK. Methodology, resources, supervision: MS. Validation, writing – review and editing: SS.

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