Case Report

Case report: Vibration response imaging findings following inadvertent esophageal intubation

[Présentation de cas: Trouvailles en imagerie par réponse vibratoire à la suite d'une intubation oesophagienne involontaire]

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Purpose: We describe the effect that inadvertent esophageal intubation has on the images and on the vibration distribution of vibration response imaging (VRI).

Clinical features: Vibration response imaging (VRI) is a novel, non-invasive, computer-based technology that measures vibration energy of lung sounds during respiration and displays regional intensity, in both visual and graphic format. Vibration response images, obtained prior to tracheal intubation (spontaneous breathing) and during endotracheal ventilation using a controlled mode, resulted in evenly distributed vibrations throughout the patient's lungs. During inadvertent esophageal ventilation, however, the majority of vibrations were detected in the upper regions of the image, compared to those of the lower (60% *vs* 8%, respectively). During spontaneous breathing and endotracheal ventilation, the midclavicular column of sensors, located over the centre of each lung, detected more vibrations compared to either the medial or the axillary column of sensors. During inadvertent esophageal ventilation, more vibrations were detected by the medial column of sensors (nearest to the midline/esophagus); and fewer were detected by the sensors that were positioned more laterally.

Conclusion: This report illustrates the potential for a visual image of distribution of lung vibration energy to differentiate endotracheal intubation from inadvertent esophageal intubation.

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***Objectif** : Nous décrivons l'effet qu'une intubation oesophagienne involontaire a eu sur les images et sur la distribution des vibrations de l'imagerie par réponse vibratoire (VRI – vibration response imaging).*

***Éléments cliniques** : L'imagerie par réponse vibratoire (VRI) est une nouvelle technologie informatique non invasive qui mesure l'énergie de vibration des sons pulmonaires pendant la respiration et affiche l'intensité régionale en format visuel et graphique. Les images de réponse vibratoire obtenues avant l'intubation trachéale (respiration spontanée) et pendant la ventilation endotrachéale à l'aide d'un mode contrôlé ont eu pour résultat des vibrations uniformément distribuées dans l'ensemble des poumons du patient. Cependant, pendant la ventilation oesophagienne involontaire, la majorité des vibrations ont été détectées dans la région supérieure de l'image, par rapport à celle de la région inférieure (60 % vs 8 %, respectivement). Durant la respiration spontanée et la respiration endotrachéale, la colonne de détecteurs médio-claviculaires situés au dessus du centre de chaque poumon a détecté davantage de vibrations que les colonnes de détecteurs médianes et axillaires. Pendant une ventilation oesophagienne involontaire, davantage de vibrations ont été détectées par la colonne médiane de détecteurs (la plus proche de la ligne médiane / œsophage) ; moins de vibrations ont été détectées par ceux situés davantage sur les côtés.*

***Conclusion** : Ce compte-rendu démontre le potentiel qu'une image visuelle de la distribution de l'énergie de vibration pulmonaire pourrait avoir pour distinguer l'intubation endotrachéale d'une intubation oesophagienne involontaire.*

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INADVERTENT esophageal or endobronchial intubation may lead to serious complications such as hypoxemia, cardiac arrhythmias and death.[1] Clinical signs of incorrect placement of the endotracheal tube have documented limitations. While capnography is a standard of practice for anesthesia, it cannot reliably distinguish between endotracheal and endobronchial tube positioning. Auscultation of breath sounds has limited sensitivity and depends on the experience of the listener.[2–8] Colorimetric end-tidal carbon dioxide detectors are simple to use, inexpensive, and have a high sensitivity and specificity to accurately differentiate between esophageal and tracheal intubation in the patient with good lung perfusion.[9] Vibration response imaging (VRI) is a novel, non-invasive, computer-based technology that measures vibration energy of lung sounds during respiration.[10–12] Unlike auscultation, VRI is not subjective and does not depend on the auditory acuity or experience of the listener. As air moves in and out of the lungs, vibrations propagate through lung tissues and are recorded by 36 sensors spatially distributed on the patient's back. A dynamic image of airflow-derived vibrations is created. Here we describe the VRI images obtained from a patient during an inadvertent esophageal intubation; and we compare it to images in the same patient during spontaneous breathing (prior to endotracheal intubation) and following endotracheal intubation, with the initiation of mechanical ventilation.

Case report

A 68-yr-old female patient, with diagnosis of lung cancer, was scheduled for elective, left upper lobectomy. She had a medical history of pneumonia, hypertension, and aortic stenosis, and a 40 year history of smoking a pack of cigarettes per day (she quit 15 years previously). A plain chest *x ray* and a computerized, axial tomography of the thorax revealed a 2-cm, spiculated, left lung mass. Bronchoscopic biopsy revealed a non-small cell lung carcinoma. Prior to surgery, her pulmonary function tests were normal. The patient had no history of difficult intubation.

After we obtained written, informed consent for her participation, we enrolled the patient in a study comparing VRI associated with unilateral *vs* bilateral ventilation in patients undergoing one-lung ventilation, as part of a thoracic surgical procedure. We established intravenous access in the operating room and applied routine monitors. Prior to tracheal intubation, we obtained baseline VRI recordings and continued serial recordings after airway instrumentation. All recordings were performed using the supine matrix (Figure 1 and refer to methods below).

We induced general anesthesia with propofol 2.0 $mg \cdot kg^{-1}$ *iv* and fentanyl 150 µg *iv*, with rocuronium 0.8 $mg \cdot kg^{-1}$ *iv* given as a bolus to facilitate tracheal intubation. The patient was easily mask ventilated with 100% O_2. Next, we performed laryngoscopy with a #3 Macintosh blade. This procedure established a grade 2 Cormack-Lehane laryngeal view, allowing us to advance a #8.0 endotracheal tube. After inflating the endotracheal tube cuff, we immediately obtained a 20-sec VRI recording; and, as the recording ended, we recognized that the endotracheal tube was in the esophagus (low expired CO_2, tachycardia and absent breath sounds). At that point, we removed the endotracheal tube and resumed mask ventilation with 100% oxygen. After reintubation, we confirmed correct endotracheal tube placement with a fibre optic bronchoscope, and VRI recordings were obtained during ventilation of both lungs. During the airway interventions, oxygen saturation never decreased below 94%. Lung isolation was achieved with an endobronchial blocker (Arndt Blocker; Cook Critical Care, Bloomington, IN, USA) placed in the left mainstem bronchus and guided with a fibre optic bronchoscope. The patient tolerated the surgical procedure uneventfully and was discharged to home five days later. This peri-induction sequence of events provided the opportunity to compare VRI recordings during controlled mechanical ventilation and inadvertent esophageal intubation.

Vibration response images

Vibration recordings were performed using a VRI device (Deep Breeze™, Or-Akiva, Israel) with two arrays of 6 rows × 3 columns sensors or microphones, similar to those used in digital stethoscopes (Figure 1). We placed each array under a lung, as the patient lay in a supine position, and performed the recording over a 20 sec period, capturing up to six respiratory cycles. A gray-scaled dynamic image was displayed 60 sec after the start of each recording; and the raw data was stored digitally on the device for later review and analysis. The maximal energy frame is the frame in the video sequence that usually provides the most information on the distribution of lung vibration and usually approximates peak inspiration. We used the image from this frame for analysis. Breath sounds, as detected by sensors on the chest wall, are the dominant signal in the gray-scale distribution. We chose a representative breath cycle for analysis, as described in detail in our recent article.[9] Numerical analysis of the intensity of vibration energy data was performed from the left and right lungs. This analysis is not dependent on the image and allows total vibration

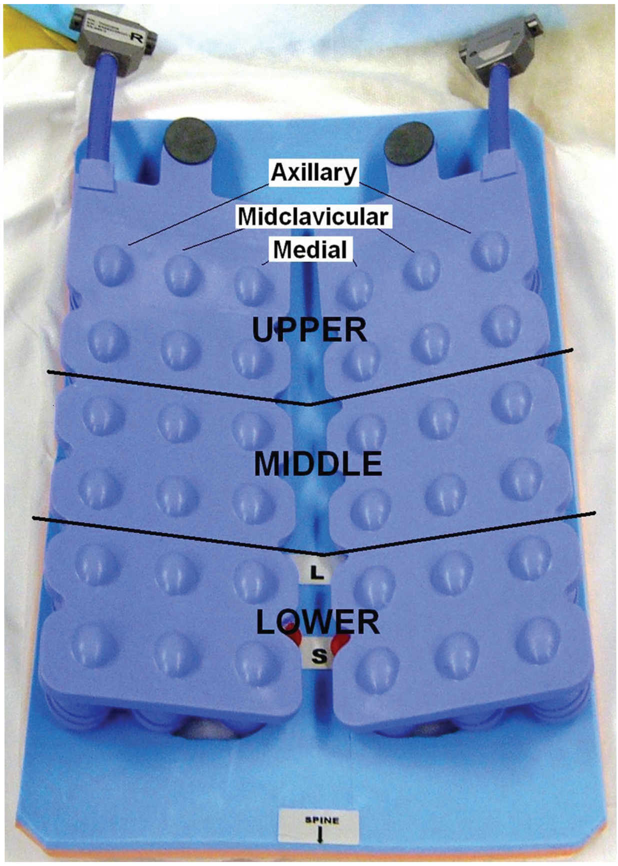

FIGURE 1 Matrix of sensors. Analysis of numerical vibration data was undertaken by grouping sensors into axial regions (upper, middle, lower) and sagittal regions (medial, midclavicular, axillary).

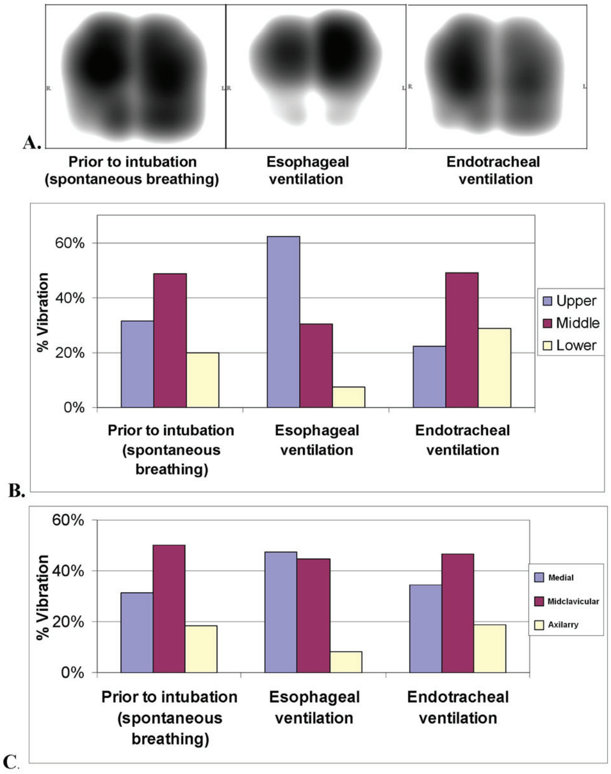

FIGURE 2 Distribution of vibrations obtained using vibration response imaging (VRI). Panel A) Vibration response images obtained prior to intubation (spontaneous breathing), esophageal intubation, and during tracheal intubation with mechanical ventilation. Panel B) Percentages of vibration energy in axial regions (upper, middle and lower regions) during the three different scenarios. Panel C) Percent vibration energy in sagittal regions (medial, midclavicular, axillary) during the three different scenarios.

energy to be compared between left and right lungs. The commercially available VRI device provides total recording comparisons for each lung. The non-commercially available software tool used in this study allowed distribution of vibration to be measured from a single frame of a recording. The proprietary software used was validated internally by the manufacturer and provides numerical vibration data from individual sensors for each frame of the video. Group sensors performed comparison of regional vibration distribution by grouping sensors into axial regions (upper, middle, lower), and sagittal regions (medial, midclavicular, axillary) (Figure 1).

Compared to VRI recordings obtained prior to intubation (spontaneous breathing) and during tracheal intubation with mechanical ventilation, the image obtained during esophageal ventilation was very different, with the majority of vibrations detected in the upper regions of the image (Figure 2A). During esophageal ventilation, 60% of the vibrations were detected by the upper sensors and 8% by the lower sensors. In contrast, images during spontaneous breathing, as well as images during endotracheal ventilation, resulted in vibrations that were more evenly distributed, with the sensors from the middle lung region detecting 50% of vibrations (Figure 2B).

Analysis of the sagittal distribution of vibration energy showed that, during esophageal ventilation (as compared to endotracheal intubation and spontaneous breathing), more vibrations were detected by the medial columns of sensors (nearest to the midline/esophagus) and fewer in the sensors that were positioned more laterally. During spontaneous breathing and endotracheal ventilation, the midclavicular columns of sensors in the centre of each lung detected more vibrations, compared to either the medial or the axillary columns (Figure 2C).

Discussion

The VRI images obtained during esophageal and endotracheal ventilation were markedly different. The image obtained during esophageal ventilation showed that vibrations were detected primarily by the upper sensors; while the image obtained during endotracheal intubation showed more homogenous distribution, with greater percentages of the total vibration occurring in the middle and lower regions. To examine the possible source of these vibrations, we examined the sagittal regional distribution of vibrations according to the three columns of sensors over each lung (medial, midclavicular, axillary). This analysis showed that, during esophageal intubation, greater vibrations were detected by the medial sensors, less by the midclavicular, and the least by the axillary sensors, consistent with vibrations emanating from the esophagus and radiating outward, with the strongest vibrations detected by the medial sensors closest to the esophagus. This vibration distribution pattern is different from that observed when both lungs are ventilated. As expected, from vibrations generated by airflow, where turbulent flow is likely to be present in the larger airways, the highest vibrations on a ventilated lung are detected by midclavicular sensors. As flow becomes more laminar in the smaller airways, fewer vibrations are detected in the periphery of a ventilated lung.

Detection of inadvertent esophageal intubation is crucial to prevent serious complications. Although our case report originates from an operating room (OR) setting where considerable airway expertise exists, our observations suggest potential applications for airway management outside the OR, where inadvertent esophageal intubation may occur, as in the hands of paramedics or where capnography, the accepted standard for objective confirmation of endotracheal tube position,[9] is not available. While the ability to use an acoustic signal as an aid in verification of endotracheal intubation has been demonstrated previously,[2,13] unlike other methods, VRI also creates a visual image of distribution of vibrations within the lung.[10,12] One such report limits the inferences which can be drawn, but may serve as a catalyst to trigger further bench studies using this technology.

The reasons for observing increased pulmonary vibrations in the upper lung regions during esophageal ventilation are unclear. These findings may possibly result from vibrations generated from pulmonary gases exiting the endotracheal tube, forcing their way through a collapsed esophagus, creating excess local vibration. Endotracheal intubation results in the rigid, open structure of the airways facilitating transmission of vibrations to the lower lung regions. In contrast, the soft and collapsed nature of the esophagus would limit transmission of vibrations along its entire length. It is unclear if this distribution of vibrations would occur in every patient. We would anticipate that all patients would demonstrate an increase in vibration levels in the medial sensors, as the esophagus is a midline structure.

One limitation of this technology is that underlying pulmonary pathology may decrease lung vibrations in the lower and the axillary lung regions, generating images similar to those seen during esophageal ventilation. Since the endotracheal tube cuff was inflated following inadvertent esophageal intubation, we cannot confirm the effect of a possible air leak on the VRI image. Finally, the lag time between the start of the VRI recording and the appearance of the image on the screen is slightly less than 60 sec, which is within the temporal scope of current methods of identifying esophageal intubation. Vibration response imaging technology has recently been approved by the U.S. Food and Drug Administration for monitoring and recording lung sounds, and by the European regulatory authority; but, as with any new technology, time and experience are required to determine the eventual "real-world" clinical applications of this technology.[14–18]

In conclusion, this case report demonstrates the VRI patterns associated with inadvertent esophageal intubation. The VRI image allows rapid visualization of vibrations derived from altered airflow patterns, which could provide additional information to assist in the differentiation of endotracheal *vs* endobronchial or esophageal positioning of the endotracheal tube. Studies are warranted to elucidate the clinical utility of this technology for airway management in both routine and specialized settings.

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References

1 *Stone DJ, Gal TJ.* Airway management. *In:* Miller RD (Ed.). Anaesthesia, 5th ed. New York: Churchill Livingstone Inc.; 2000: 1414–51.

2 *O'Connor CJ, Mansy H, Balk RA, Tuman KJ, Sandler RH.* Identification of endotracheal tube malpositions using computerized analysis of breath sounds via elec-

tronic stethoscopes. Anesth Analg 2005; 101: 735–9.

3 *Alliaume B, Coddens J, Deloof T.* Reliability of auscultation in positioning of double-lumen endobronchial tubes. Can J Anaesth 1992; 39: 687–90.

4 *Andersen KH, Schultz-Lebahn T.* Oesophageal intubation can be undetected by auscultation of the chest. Acta Anaesthesiol Scand 1994; 38: 580–2.

5 *Knapp S, Kofler J, Stoiser B, et al.* The assessment of four different methods to verify tracheal tube placement in the critical care setting. Anesth Analg 1999; 88: 766–70.

6 *Verghese ST, Hannallah RS, Slack MC, Cross RR, Patel KM.* Auscultation of bilateral breath sounds does not rule out endobronchial intubation in children. Anesth Analg 2004; 99: 56–8.

7 *Raphael DT, Crookes P, Arnaudov D, Benbassat M.* Acoustic reflectometry esophageal profiles minimally affected by massive gas ventilation. Am J Emerg Med 2005; 23: 747–53.

8 *Sugiyama K, Yokoyama K, Satoh K, Nishihara M, Yoshitomi T.* Does the Murphy eye reduce the reliability of chest auscultation in detecting endobronchial intubation? Anesth Analg 1999; 88: 1380–3.

9 *Menegazzi JJ, Heller MB.* Endotracheal tube confirmation with colorimetric CO2 detectors. Anesth Analg 1990; 71: 441–2.

10 *Dellinger RP, Jean S, Cinel I, et al.* Regional distribution of acoustic-based lung vibration as a function of mechanical ventilation mode. Crit Care 2007; 11: R26.

11 *Dellinger RP, Parrillo JE, Kushnir A, Rossi M, Kushnir I.* Dynamic visualization of lung sounds with a vibration response device: a case series. Respiration 2007; doi: 10.1159/000103558.

12 *Cinel I, Jean S, Gratz I, Deal E, Tay C, Littman J.* Acoustic monitoring of one-lung ventilation with vibration response imaging. Crit Care 2007; 11(Suppl 2): P202.

13 *Tejman-Yarden S, Lederman D, Eilig I, et al.* Acoustic monitoring of double-lumen ventilated lungs for the detection of selective unilateral lung ventilation. Anesth Analg 2006; 1003: 1489–93.

14 *Tomaske M, Gerber AC, Stocker S, Weiss M.* Tracheobronchial foreign body aspiration in children - diagnostic value of symptoms and signs. Swiss Med Wkly 2006; 136: 533–8.

15 *Mor R, Kushnir I, Meyer JJ, Ekstein J, ben-Dov I.* Breath sound distribution images of patients with pneumonia and pleural effusion. Respir Care 2007; 52: 1753–60.

16 *Bentur L, Livnat G, Husein D, Pollack S, Rotschild M.* Dynamic visualization of breath sound distribution in suspected foreign body aspiration: a pediatric case series. Journal of Bronchology 2007; 14: 156–61.

17 *Kramer MR, Raviv Y, Hardoff R, Shteinmatz A, Amital A, Shitrit D.* Regional breath sound distribution analysis in single-lung transplant recipients. J Heart Lung Transplant 2007; 26: 1149–54.

18 *Kramer MR.* Dynamic visualization of breath sound distribution: can we see the voices? Journal of Bronchology 2007; 14: 142–3.