ACOUSTIC MONITORING OF DOUBLE LUMEN VENTILATED LUNGS FOR THE DETECTION OF SELECTIVE UNILATERAL LUNG VENTILATION

Abstract:
One lung intubation (OLI) is among the most common complications following endotracheal intubation. To date, none of the monitoring tools has proved effective for its early detection. The aim of this study is to investigate the efficacy of acoustic analysis for the detection of OLI. We collected lung sounds from eleven patients undergoing thoracic surgery requiring the placement of a double lumen tube. Recordings of separate lung ventilation were performed after induction and confirmation of adequate tube positioning, before surgery. Samples of lung sounds were collected by three piezoelectric microphones, one on each side of the chest and one on the right forearm, for background noise sampling. The samples were filtered, the signals’ energy envelopes were calculated, and breath sound segmentation to breath and rest periods was performed. Each respiration was classified into one of three categories - bilateral ventilation, selective right lung ventilation or selective left lung ventilation, based on the ratio between energy of the breath signal of each lung signal’s energy ratio. The results show that OLI was accurately identified in ten of the eleven patients during right OLI and in all eleven patients during left OLI. This preliminary study suggests that acoustic monitoring is effective for the detection of selective lung ventilation and may be useful for early diagnosis of OLI.
Introduction

Inadvertent endobronchial intubation or one lung intubation (OLI) was reported as the most common complication of endotracheal intubation by the Australian Incident Monitoring Study Analysis. It accounted for 79 of the 189 reported incidents (1). OLI is particularly common during pediatric anesthesia and laparoscopic surgery (2,3) and may lead to serious complications such as atelectasis of the non-ventilated lung, pneumothorax, hypoxemia, cardiac arrhythmias and hypotension (4). To date, none of the techniques used to monitor intubated patients has proved reliable for the early detection of OLI before the appearance of clinical signs.

Auscultation of breath sounds, used in daily practice to confirm the correct positioning of the endotracheal tube in the operating room or in the intensive care unit, was found to be inaccurate for the detection of OLI (5-7), with an unacceptably high margin of error that can reach up to 60% (4). Pulse oxymetry for oxygen saturation monitoring is considered a good method for OLI detection (8,9). The Australian Incident Monitoring Analysis reported that pulse oxymetry was used to detect 87% of the OLI incidents. But oxymetry results have a latency of 2 to 5 minutes, becoming apparent only after the patient becomes hypoxemic, without providing any indication as to the reason of the hypoxemia (1). Capnography was suggested in the past, but has proved to be a poor method to identify OLI (10,11). New techniques for ventilation monitoring are being developed and studied. Online spirometry has been studied and reported to have several limitations (12). Acoustic reflectometry, a method based on an area-distance profile used to distinguish between tracheal and esophageal intubations (13), was found to be useful in the detection of OLI in a patient undergoing laparoscopic surgery (14), but no further validation of this method has been provided.
A preliminary study by Sod-Moriah et al. demonstrated that non-invasive monitoring of lung sounds by placement of a microphone on each side of the chest was useful for the monitoring of differential lung ventilation in dogs, detecting 89% of the cases with selective right OLI and 90% of the cases with selective left OLI (15-18). These encouraging results lead us to try this monitoring technique on human patients. In order to sample selective OLI, we sampled patients intubated for general anesthesia with a double lumen tube. This ventilation technique enabled us to obtain lung sounds during only right, only left and bilateral lung ventilation by clamping one side of the tube and ventilating the other.

The aim of the present study is to validate the accuracy of an acoustic sensor device for the detection of selective OLI in human patients ventilated with a double lumen endotracheal tube.
Table 1. A confusion matrix of OLI recognition as determined by the algorithm, compared to the correct ventilation status. The values in the numerator are the correctly recognized cases and in the denominator the number of trials for this specific condition.

<table>
<thead>
<tr>
<th>True ventilation status</th>
<th>Right OLI</th>
<th>Left OLI</th>
<th>Bilateral</th>
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<tbody>
<tr>
<td>Right OLI</td>
<td>10/11</td>
<td></td>
<td>1/11</td>
</tr>
<tr>
<td>Left OLI</td>
<td></td>
<td>11/11</td>
<td></td>
</tr>
<tr>
<td>Bilateral</td>
<td></td>
<td></td>
<td>11/11</td>
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</tbody>
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Legends for figures

Fig. 1. Patterns of sampled lung sounds recorded from the patients: box a is an unfiltered lung sound sample from the right chest, box c is the same sample after filtration. Box b is a recording of the same trial from the left chest and box d is the same sample after filtration. For the first 23 seconds both lungs were ventilated, after 23 seconds the right tube was clamped and only the left lung was ventilated and after 45 seconds the right tube was unclamped and the left side tube was clamped so that only the right lung was ventilated.

Fig. 2. Signal processing of the sample in Fig. 1. In boxes a and b the samples are shown in greater detail following segmentation. In boxes c and d the energy envelope is shown for each respiration. Each respiration is classified into Tr (tracheal ventilation), Rt (right OLI) and Lt (left OLI). The classification for each respiration appears between the boxes of the right and left samples.

Fig. 3. Recordings of lung sounds and signal processing. In this trial after 40 seconds, during Rt OLI the algorithm incorrectly classified the respiration as Tr.
Figure 1
Figure 2
Figure 3