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Revisiting the Video Stethoscope: An Application of Digital Signal Processing Software (Goldwave ®) to Monitoring Ventilation in Intubated Patients

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Abstract— **Problems with tracheal intubation and mechanical ventilation are potentially important causes of perioperative morbidity and mortality. We have developed a method of monitoring the ventilation of both lungs during general anesthesia that is an advanced digital version of a more primitive analog technique developed over two decades ago. We used two miniature electret microphones connected to regular chest pieces, placing the assemblies on the anterior chest wall about 4 inches below the clavicle in the midclavicular line. After amplification and 16-bit analog-to-digital conversion, the digital signal processing software package Goldwave (Version 5.12, www.goldwave. com) was used to produce real-time X-Y plots of the signals, with sounds from the right side plotted on the horizontal axis and sounds from the left side plotted on the vertical axis. Recognizing that when two signals are identical, their X-Y plot should form a 45 degree line, we hypothesized that X-Y plots obtained under endobronchial conditions would be recognizably different to plots reflecting normal bilateral lung ventilation. We also hypothesized that as a result of noise and anatomical variations that under conditions of bilateral mechanical ventilation the obtained plot would be very different from a simple 45 degree line. The data obtained supports these hypotheses. This preliminary study suggests that our technique may help provide a practical real-time warning system for detecting endotracheal tube malpositions, and may help build on the work of other investigators.**

Keywords—**Breath Sounds, Patient Monitoring**

Introduction

Tracheal intubation involves placement of a disposable cuffed breathing tube (endotracheal tube or ETT, Figure 1), usually with the aid of an instrument called a laryngoscope [1]. Following placement of the ETT, usually under general anesthesia, the patient is generally mechanically ventilated using a positive-pressure ventilator.

Unfortunately, problems with tracheal intubation and mechanical ventilation are potentially important causes of perioperative morbidity and mortality [2]. Usually the ETT is placed with its tip located 1 to 3 cm above the carina, where the trachea divides into the two mainstem bronchi, allowing both lungs to be mechanically ventilated (Figure 1). However, the ETT can sometimes migrate beyond the carina into one of the mainstem bronchi, with the result that only one lung is ventilated. Means to detect this situation may be of clinical value, since one-lung ventilation can result in hypoxemia as well as atelectasis in the unventilated lung.

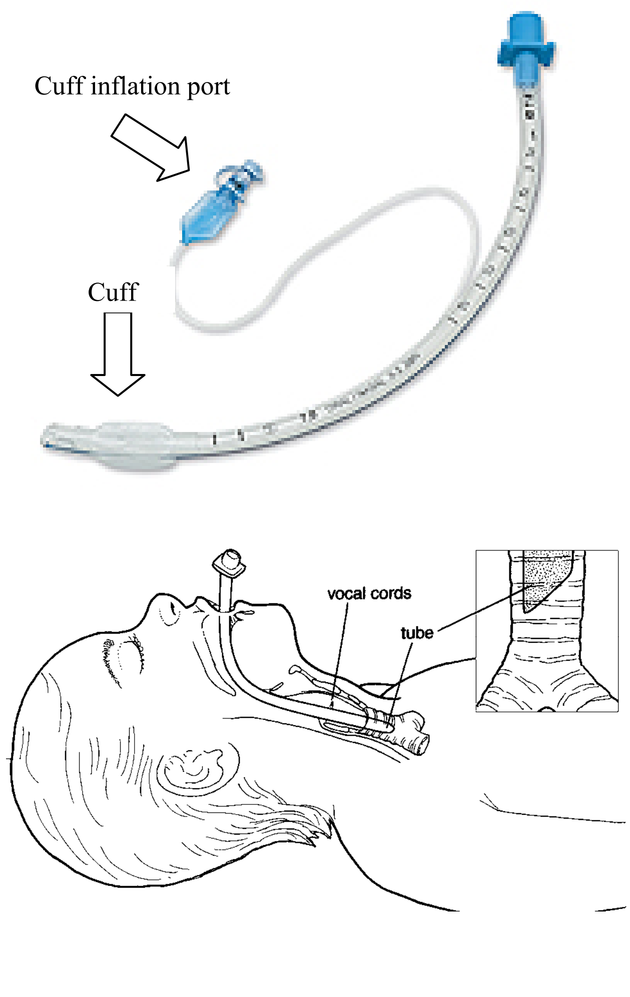

Figure 1. Cuffed endotracheal tube (top) positioned in the trachea with its tip located above the carina to ensure bilateral lung ventilation (bottom).

Hypothesis

Recognizing that when two signals are identical, their X-Y plot should form a 45 degree line, we hypothesized that X-Y plots obtained under endobronchial conditions would be recognizably different to plots reflecting normal bilateral lung ventilation. We also hypothesized that as a result of noise and anatomical variations that under conditions of bilateral mechanical ventilation the obtained plot would be very different from a simple 45 degree line.

Methods

We used two miniature electret microphones (Radio Shack 30-3013), each connected to a precordial chest piece via rubber tubing. After amplification and 16-bit analog-to-digital conversion, the digital signal processing software package Goldwave (Version 5.12, www.goldwave.com) was used to produce real-time X-Y plots of the signals, with sounds from the right side plotted on the horizontal axis and sounds from the left side plotted on the vertical axis. Later, a custom-written LabVIEW program was written to perform a similar analysis, but with enhanced flexibility; results of this undertaking will be reported elsewhere.

Results

In part one of our study we were interested in seeing what results would be obtained if the acoustic signal from an esophageal stethoscope were routed to both microphones via a Y-piece fashioned from an inexpensive stethoscope. Theoretically, since the same acoustic signal is being presented to both microphones, the X-Y plot should be a 45 degree straight line. Deviations from a perfect 45 degree line can be explained as being due to differences between the two microphones, the amplification process and the process of analog-to-digital conversion, as is illustrated in Figure 2.

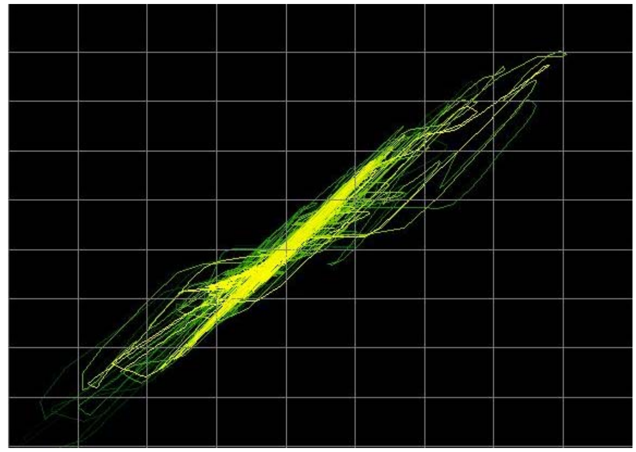

Figure 2. X-Y plot obtained when the breath sound / heart sound signal from an esophageal stethoscope was routed to both microphones via a Y-piece fashioned from an inexpensive stethoscope. Deviations from a perfect 45 degree line noted here can be explained as differences between the two microphones, the amplification process and the process of analog-to-digital conversion.

In part two we connected each microphone to a precordial chest piece with rubber tubing and placed both assemblies next to each other on the right anterior chest wall about 4 inches below the clavicle in the midclavicular line. The X-Y plot obtained is shown in Figure 3 below.

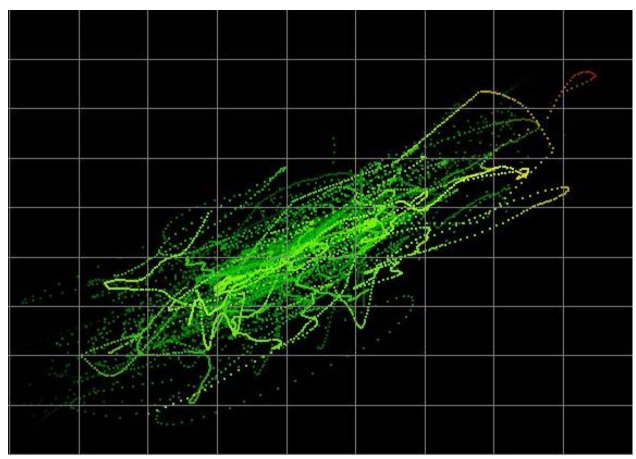

Figure 3. Control recording with both microphone assemblies placed on the right anterior chest wall about 4 inches below the clavicle in the midclavicular line. Under these conditions both microphones are presented with a similar breath sound signal and the result of the X-Y plot display is a scatter plot roughly angled at 45 degrees.

In part three we positioned each assembly on the left and right anterior chest wall about 4 inches below the clavicle in the midclavicular line. Typical results are shown in Figure 4.

We were also able to obtain a recording under conditions of inadvertent endobronchial intubation. This is illustrated in Figure 5. Note how the X-Y plot obtained is flattened out.

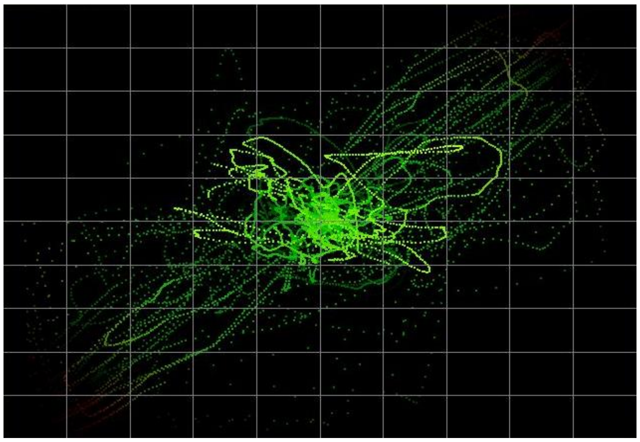

Figure 4. Recording obtained with both microphone assemblies placed on the left and right anterior chest wall about 4 inches below the clavicle in the midclavicular line. Note that the deviation form the ideal 45 degree line is even more obvious in this instance, in part because the left lung (which has two lobes) and right lung (which has three lobes) have anatomical differences that might be expected to result in even more scatter in the X-Y scatterplot.

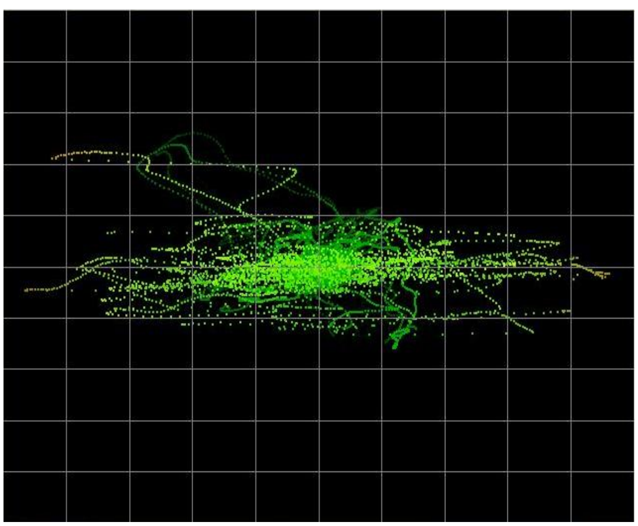

Figure 5. Recording obtained with inadvertent endobronchial (right-side only) intubation, where the left lung was not being ventilated. Note how the X-Y plot obtained is flattened out. Of interest, this situation was not initially noticed clinically in that the patient's airway pressures and oxygenation did not appear to adversely impacted. However, once the ETT was pulled back by 3 cm the bilateral ventilation pattern illustrated in Figure 4 was obtained.

In a final part of the study we momentarily discontinued positive pressure ventilation (Figure 6). Here, only the effects of background noise (which can be considerable in many operating rooms) is present.

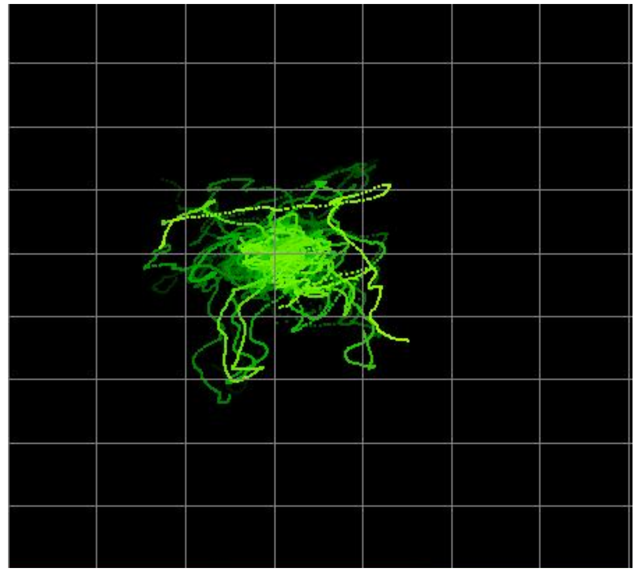

Figure 6. Recording obtained with the ventilator temporarily turned off, revealing background noise effects.

Discussion

The problem of inadvertent endobronchial intubation with its potential attendant problems of hypoxemia and pulmonary atelectasis has been a concern since the development of the endotracheal tube decades ago. Various methods can be used to ensure that unplanned endobronchial intubation has not occurred. These include techniques such as periodic auscultation of the chest bilaterally by the anesthesiologist, use of a fiberoptic bronchoscope placed down the ETT, and radiographic methods. However, none of these techniques are suitable for continuous monitoring, and the development of a reliable and inexpensive automatic method of analysis that would offer easily recognized patterns for various ETT malpositions would be potentially valuable in clinical practice.

Attempts to deal with this problem electronically have been in development for some time. For instance, in 1983 Huang et al. [3] described their experience using an ordinary oscilloscope for these purposes. They performed high-pass filtering on their data using a cuff-off frequency of 200 Hz, and describe obtaining "cotton-ball" patterns similar to the patters reported herein, as well as results for esophageal intubation and for laryngospasm.

O'Connor at al [4] studied breath sounds using electronic stethoscopes placed over each hemithorax and epigastrium to determine their ability to detect ETT malposition. After intubation the ETT was bronchoscopically positioned 3 cm above the carina, after which 3 breaths of 500 mL were given and breath sounds were recorded. A second ETT was then placed in the esophagus and the same series of breaths and recordings were performed. Finally, the tracheal ETT was advanced into the right mainstem bronchus and breath sounds were recorded. The breath sounds were digitized and filtered (300-600 Hz bandpass), and acoustic signals and left/right energy ratios were obtained for all 3 positions. Their technique was able to accurately identify all esophageal and endobronchial intubations but did not aim to provide a visual display for the clinician to monitor.

More recently, Tejman-Yarden et al. [5] used a Multiple Input Multiple Output, multidimensional Auto-Regressive model for this purpose.

While we were successful in getting interesting results using an inexpensive commercial software package for this study, we identified several issues we hope to address in future work.

First, Goldwave lacks flexibility in how it carries out X-Y plots, and does not offer the ability to adjust the X-Y plot buffer size or the time between displayed samples. Such flexibility would likely prove to be useful in determining which display parameters are best used to detect endobronchial intubation.

Secondly, we did not filter the obtained signals prior to constructing the X-Y plot. However, it is very likely that band-pass filtering would be helpful in reducing come of the effects of ambient noise. For instance, Huang et al. [3] used a high-pass filter arrangement with a cuff-off frequency of 200 Hz while O'Connor at al [4] and Mansy et al. [6] used a 300 to 600 Hz bandpass filter.

Third, for practical and clinical reasons we positioned each microphone assembly on the left and right anterior chest wall about 4 inches below the clavicle in the midclavicular line. It is certainly possible that better quality recordings might be obtained using other recording sites, although obtaining recordings from the lateral chest wall may dictate that special effort be expended to ensure that the microphone assembly does not fall off. The use of products such as the Androsonix disposable biological sound sensor (containing an adhesive backing which is affixed directly to the patient's skin) may be particularly useful in such a setting (see www.andromed.com for more information).

A final plan for further work involves employing the popular LabVIEW platform [7,8] for further development rather than continuing using Goldwave. This effort has already begun. The primary advantage of taking this step would be the enormous power and flexibility that the LabVIEW platform offers. Disadvantages include the not inconsiderable cost of LabVIEW and the need to master a complex but powerful graphical programming environment.

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