New Methods of Respiratory Monitoring

Technical and Clinical Challenges

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The Respiratory Monitoring Problem

• An increased emphasis on postoperative pain control has resulted in aggressive use of opiates for pain control (e.g. PCA morphine).
• Patients with obesity or obstructive sleep apnea are increasingly common in the USA and elsewhere.
• Existing methods of respiratory monitoring for postoperative ward patients have serious drawbacks.
Airway Issues
More Airway Issues

Renuka Reddy Bankulla, MD, is allegedly the anesthesiologist who sedated Joan Rivers at Yorkville Endoscopy.
Tracheal Intubation
“An esophageal intubation is no sin, but there is great sin in not recognizing such a placement.”

Right hole (entrance to lungs)

Wrong hole (entrance to esophagus)
Respiratory Monitoring Technologies

- Ancient methods
- Arterial blood gas analysis
- Capnography
- Pulse oximetry
- Spirometry (volume of air inhaled and exhaled)
- Thermistor-based methods
- Methods based on photoplethysmography
- Methods based on electrical impedance
- Methods based on piezoelectric film sensors
- Methods based on exhaled humidity
Ancient Methods of Respiratory Monitoring

- Watch breathing pattern *(chest, abdomen etc.)*
- Feel breath on hand placed over mouth
- See fog on mirror placed over the mouth
- Movement of little piece of cloth under nose

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Arterial Blood Gas Analysis

Is there a problem?

What is the problem?

What is to blame?

**pH:**
- Acidosis or Alkalosis?
  - pH < 7.35
  - pH > 7.45

**Acidosis:**
- CO₂ is high or HCO₃⁻ is low

**Alkalosis:**
- CO₂ is low or HCO₃⁻ is high

**Which readings fit with the change in pH?**

- CO₂ is high: Respiratory acidosis
- HCO₃⁻ is low: Metabolic acidosis
- CO₂ is low: Respiratory alkalosis
- HCO₃⁻ is high: Metabolic alkalosis

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**Right radial artery**

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### Analyte Normal Value Normal Range*

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Normal Value</th>
<th>Normal Range*</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.40</td>
<td>7.35 to 7.45</td>
</tr>
<tr>
<td>PaCO₂ (mmHg)</td>
<td>40</td>
<td>35 to 45</td>
</tr>
<tr>
<td>HCO₃⁻ (mmol/L)</td>
<td>24</td>
<td>21 to 28</td>
</tr>
<tr>
<td>PaO₂ (mmHg)</td>
<td>100</td>
<td>80 to 110</td>
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</tbody>
</table>
Pulse Oximetry

http://www.oximetry.org/pulseox/principles.htm
http://www.daviddarling.info/images/pulse_oximeter.jpg
Thermistor-based Methods

[Diagram showing a thermistor circuit and a thermistor curve graph with temperature and resistance values.

- CPU and electronics
- Thermal sensors for nasal flow
- Indicator light
- Permanent electrochemical display
- Thermal sensor for oral flow
- Miniature 3V lithium battery]
Color Spectrogram Analysis

• Voice analysis
• Voiceprint identification
• Birdcall analysis
• Heart sound analysis
• Respiratory sound analysis
Color Spectrogram of the Singing Voice

http://www.visualizationsoftware.com/gram.html
Forensic voice analysis is based on the principle that each voice is sufficiently characteristic to distinguish it from others. Factors in determining voice uniqueness lie in the size and configuration of the vocal cavities (throat, nasal, and oral cavities) and the shape, length and tension of the vocal cords. Another factor is the manner in which the articulator muscles are manipulated during speech.

Modified from http://www.stutchmanforensic.com/
Setting up your own bioacoustics laboratory
(at almost no cost !)

www.visualizationsoftware.com
Spectrogram (Version 16)
Freeware
Color Spectrogram of the Song of the Prothonotary Warbler

http://www.visualizationsoftware.com/gram.html
Application to Heart Sound Analysis
Color spectrogram analysis of a normal phonocardiogram, showing the first and second heart sounds. The signal intensity is colored as follows: red > yellow > green > blue > black. Note that the vertical axis is logarithmic while the horizontal axis is linear. The time-domain phonocardiogram is shown at the top.
Spectrogram obtained from an individual known to have a pansystolic murmur. Note that the first and second heart sounds are completely obscured by the murmur.
Application to Respiratory Sound Analysis
Respiratory Monitoring Using Color Spectrographic Analysis
Respiratory Sound Analysis: Possible Recording Sites

- Anterior or posterior chest wall
  *(use two microphones to detect one-lung ventilation)*
- LMA / ETT cuff inflation port
  *(requires special leak-free microphones)*
- “Mustache” (nasolabial) microphone
- Microphone in oxygen mask
- Microphone in ear canal
“Mustache” (nasolabial) microphone

RED > YELLOW > GREEN > BLUE > BLACK

Respiratory spectrogram obtained during sleep.
Sample color spectrogram of eight respiratory cycles of breath sounds (inspiration plus expiration) obtained from the LMA in a spontaneously breathing patient under general anesthesia. Note that the inspiratory phase of the signal lasts somewhat longer than the expiratory phase and has slightly less high frequency components. Note also that there is little or no signal energy beyond 900 Hz. The cardiac monitor "beep" associated with each heart beat (918 Hz) is also visible near the top. At the very top is displayed the raw time-domain signal. The audio portion of this recording may be downloaded and played on suitably equipped computers by visiting [http://lmamonitor.homestead.com](http://lmamonitor.homestead.com).

[Color scale: RED > YELLOW > GREEN > BLUE > BLACK]

*From [http://www.cja-jca.org/cgi/content-nw/full/50/suppl_1/A113/F](http://www.cja-jca.org/cgi/content-nw/full/50/suppl_1/A113/F)*
RED > YELLOW > GREEN > BLUE > BLACK
COLOR SPECTROGRAPHIC RESPIRATORY MONITORING FROM THE EXTERNAL EAR CANAL
COLOR SPECTROGRAPHIC RESPIRATORY MONITORING FROM THE EXTERNAL EAR CANAL
COLOR SPECTROGRAPHIC RESPIRATORY MONITORING FROM THE EXTERNAL EAR CANAL

Breath holding
The End

Thank You for Listening