AURA: A NEW RESPIRATORY MONITOR AND APNOEA ALARM FOR SPONTANEOUSLY BREATHING PATIENTS

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SUMMARY

Previous attempts to introduce non-invasive monitoring of ventilation of spontaneously breathing patients into routine practice have been unsuccessful. The Aberdeen University Respiratory Alarm (AURA) allows such monitoring by utilizing the pyroelectric property of polarized polyvinylidene fluoride sensors to detect temperature changes that occur during breathing into an oxygen delivery face mask. A quartz crystal oscillator generates pulses that allow measurement of interexpiratory time and ventilatory frequency. The system incorporates LED digital displays, a bargraph and audiovisual alarms. An analog output permits display and analysis of the sensed signals. AURA performed satisfactorily in both volunteer studies and six patients in the clinical setting. AURA may be an appropriate respiratory transducer in those patients requiring oxygen therapy.

KEY WORDS


Standards for monitoring during anaesthesia and in the recovery period have received increasing attention in recent years [1–4]. Unfortunately, all currently available anaesthetic techniques leave the patient at risk of respiratory depression which may extend well into the postoperative period as efforts are made to maximize patient analgesia and comfort. Although a useful monitor of tissue oxygenation, pulse oximetry has several limitations as a monitor of respiratory depression and apnoea [5].

Several techniques have been developed to solve the difficult task of monitoring ventilation in the spontaneously breathing patient [6–16]. However, to date there are few convenient non-invasive techniques available to measure and display routinely breath-to-breath variability or to allow early detection of apnoea in spontaneously breathing patients at risk.

The Aberdeen University Respiratory Alarm (AURA) [17] is a respiratory monitor and apnoea alarm system for spontaneously breathing patients receiving supplementary oxygen via a face mask. AURA measures and displays ventilatory frequency in breaths per minute and interexpiratory time in seconds. It has been designed to be non-invasive, incorporated within the most common means of oxygen administration and reliable in the presence of both patient movement and variable gas flows.

METHODS

The AURA system is based on three modules: sensor, timing and display. Figure 1 illustrates the interrelationships of these modules in a functional block diagram. A transformer-coupled power supply with a distribution board form an integral part of the system within a single housing. The sensor material used was polarized polyvinylidene fluoride (PVDF) which has both piezo- and pyroelectric properties [18]. Two PVDF sensor strips are mounted on the inside of an oxygen face mask (fig. 2) in a differential configuration so that the output of one sensor is compared with the output of the other. A difference in temperature

between the two surfaces of each PVDF strip results in the development of a potential difference that is directly proportional to the rate of change of temperature. PVDF has low water absorption characteristics, easy configuration and is chemically inert.

The sensed signals are filtered, a.c.-coupled to a differential amplifier and subsequently undergo further filtering. A gain control permits adjustment of these signals, which are buffered to a bargraph display and compared with a precision reference voltage before being latched. The timing
module consists of a 32768-Hz quartz crystal oscillator which generates pulses that are divided down to a number of reference frequencies, permitting measurement of the interexpiratory time (IET) and rate (f) and refreshing the digital displays. The timing module also drives the logic associated with the system. Two banks of switches govern EPROMS that allow the user to set the timing of alarms for f and maximum IET. The display and alarm modules include the logic to drive and respond to the alarm signals generated by the system.

The displays include: a bargraph and a soft audible click with each expiration, a double digit LED display of f and IET. A single audio alarm, and two red LED indicate the cause of the alarm. An analog output allows display and further analysis of sensed signals by a microprocessor. Before use, alarms are selected and checked. The mask is then applied to the face and the gain adjusted until the signal is optimal as indicated by the bargraph display.

Initial evaluation of AURA as a monitor of ventilation was carried out in volunteers, and the sensed signals obtained in the laboratory were compared under conditions of varying gas flows, movement and varying pauses between breaths. After local Ethics Committee approval, we recorded observations in six adult patients who were monitored in the postoperative recovery room for periods of 15–25 min while one of the authors (A.M.C.) observed the patients continuously during each evaluation period.

RESULTS

Ambient temperatures for the volunteer studies were in the range 18–24 °C. Figure 3A and B show samples of typical signals recorded in the laboratory environment. The amplitudes of retrieved signals were in the range 40–400 mV; figure 3A illustrates this breath-to-breath variability, underlining the importance of setting the gain to an adequate level. Figure 3C demonstrates that varying the oxygen flow rate had only a small effect on the signal.

Ambient temperatures for the clinical study were 23–24 °C. Three female and three male adult patients (ages 27–64 yr) were monitored in the postoperative recovery ward. Table I presents clinical details of these patients and the results obtained. There was a wide range of values of IET and f. There was a variability of signal amplitudes within the clinical setting (42–320 mV) similar to that observed in laboratory studies. Figure 3D shows a typical signal recorded in a patient and includes an episode of apnoea; apnoeic periods were recorded in two patients (maximum durations of 11 s and 23 s). Subsequently, we have tested the instrument on another 12 patients and have found similar signal patterns during episodes of airway obstruction and apnoea. Excessive movements involving displacement of the mask were noted to produce signal artefacts and false positive alarms.

DISCUSSION

Ventilation in spontaneously breathing patients is currently monitored by ward staff who record the ventilatory frequency at intermittent intervals.
Heavy demands on nursing staff makes continuous monitoring of ventilation in the spontaneously breathing patient an impossible ideal within the typical postoperative surgical or recovery ward setting. AURA is a novel non-invasive approach to monitoring spontaneous ventilation that has been found quick to prepare (less than 90 s), easy to use and unobtrusive. Nursing staff have commented favourably on the displays of ventilatory frequency, while the

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**TABLE I. Patient data and results.**

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>Age (yr)</th>
<th>Sex</th>
<th>Operation</th>
<th>Monitoring time (min)</th>
<th>$f$ (b.p.m.) (max/min)</th>
<th>IET(s) (max/min)</th>
<th>Peak signal (mV) (max/min)</th>
<th>Apnoea (s)</th>
<th>False + ve</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>33</td>
<td>F</td>
<td>Pacemaker insertion</td>
<td>25</td>
<td>18/5</td>
<td>11/2</td>
<td>203/81</td>
<td>11</td>
<td>---</td>
<td>Poor mask tolerance</td>
</tr>
<tr>
<td>2</td>
<td>41</td>
<td>F</td>
<td>Sigmoidoscopy</td>
<td>20</td>
<td>17/13</td>
<td>7/2</td>
<td>196/108</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>3</td>
<td>27</td>
<td>M</td>
<td>Excision of pilonidal sinus</td>
<td>15</td>
<td>14/9</td>
<td>8/3</td>
<td>226/132</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>4</td>
<td>64</td>
<td>F</td>
<td>Cervical lymph node biopsy</td>
<td>25</td>
<td>15/6</td>
<td>23/2</td>
<td>110/53</td>
<td>23</td>
<td>---</td>
<td>Movement artefact</td>
</tr>
<tr>
<td>5</td>
<td>48</td>
<td>M</td>
<td>Repair left inguinal hernia</td>
<td>22</td>
<td>36/17</td>
<td>3/1</td>
<td>226/42</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>6</td>
<td>33</td>
<td>M</td>
<td>Repair of bilateral inguinal hernia</td>
<td>23</td>
<td>22/13</td>
<td>5/1</td>
<td>320/124</td>
<td>---</td>
<td>2+</td>
<td>Varying signal amplitude</td>
</tr>
</tbody>
</table>
system's audio and visual alarms were helpful in the early identification of patients with intermittent airway or ventilation problems.

Signals were recorded despite patient movement, talking or coughing, the presence of a nasogastric tube, absence of dentition, or presence of an oropharyngeal airway. All visually noted apnoeic episodes that exceeded the IET alarm settings were detected. It was felt unlikely that these apnoeic episodes would have been noticed if the alarm had not been activated. Setting the gain control at too low a value led to false positive alarms.

Mask position was not found to be critically important, but it was necessary for it to overlie either mouth or nose, and preferably both. It was noted that less gain was required when the two sensors overlay the nares and lower lip or when an oropharyngeal airway was in situ. The incidence of signal artefact was low except during gross movements resulting in mask displacement. Alarms triggered in this instance acted as an indicator of patient compliance to their prescribed oxygen therapy. With the aid of a microprocessor-based evaluation technique, signal filtering, display of monitored variables and alarms are now being improved. We are also investigating the optimal number, size and configuration of sensors within the mask.

Observations of ventilatory frequency have been reported as an indicator of impending respiratory dysfunction [19]. AURA would be an appropriate respiratory transducer in those patients requiring oxygen therapy. We are currently assessing the system in a larger series of patients at risk of apnoea on the intensive care unit, the respiratory medicine ward, and post-operative surgery ward.

REFERENCES