The PEP transducer: a new way of measuring respiratory rate in the non-intubated patient

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Abstract

Objectives—To explore the use of a pyroelectric polymer (PEP) film as a transducer for a simple respiratory rate monitor and to evaluate the transducer in a laboratory situation.

Methods—Laboratory evaluation of a new pyroelectric transducer for measurement of respiratory rate.

Results—The amplified output from the pyroelectric film produced an excellent respiratory trace when used on a normal spontaneously breathing subject. The transducer is cheap, robust, and reliable.

Conclusions—PEP films have the potential to be used as cheap and effective transducers in respiratory rate monitors for non-intubated patients. In the laboratory, they have many desirable characteristics which should now be evaluated in a clinical setting.

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Respiratory rate is one of the most important physiological parameters. It is a component of most medical and nursing records and is used in many clinical scoring systems. Extremes of respiratory rate indicate the need for urgent intervention.^{1,2} Moreover, without this parameter, it is impossible to calculate the revised trauma score. This has caused problems for major trauma outcome studies in both the US³ and the UK, where, in 1995, 60% of trauma patients did not have their initial respiratory rate recorded (personal communication).

Until the widespread introduction of capnography in the last decade, the measurement of respiration in clinical medicine was dependent on observation alone, although this is known to be highly inaccurate.^{4,5} The ability to monitor cyclical changes in carbon dioxide concentration with an infrared transducer provided a reliable way of measuring respiratory rate in a patient with an endotracheal tube in situ.

There remains, however, an acknowledged need to monitor respiration in the non-intubated patient.^{6,7} Capnography has recently been used for this purpose but a nasal cannula is required to allow accurate sampling of exhaled air.⁸ Moreover, the equipment is delicate, expensive, and requires frequent calibration. In the early part of this decade, electrocardiographic (ECG) monitors came onto the market which used changes in transthoracic impedance to detect respiration.

Their apparent simplicity of use—they require only the standard ECG electrodes for both ECG and respiration monitoring—led to calls for their widespread introduction.^{6,9,10} Unfortunately, there are several problems with impedance monitors in clinical usage:

- They are extremely sensitive to patient movements.
- They have slow response times.
- The respiratory tracing is usually of poor quality.
- They are very slow to recognise apnoea.

Many other methods of monitoring respiration have been described but have also been unsuitable for the clinical situation. These have included more sophisticated impedance pneumography,¹¹ nasal thermocouples,¹² acoustic sensors,¹³⁻¹⁵ fiberoptic sensors,¹⁶⁻¹⁸ extensometers,¹⁹ and signal processing of photoplethysmographic and other pulse waveforms.^{20,21}

Ten years ago pyroelectric polymers (PEPs) became readily available. These thin plastic films are self exciting materials which respond to changes in temperature (pyroelectric effect) and also to changes in pressure (piezoelectric effect). As pyroelectric transducers, they were studied by scientists in many disciplines and researchers noted that if a small piece of PEP was incorporated into a face mask it could be used to monitor the respiratory cycle.^{22,23} The concept has lain dormant for a decade while the problem of measuring respiration in the non-intubated patient remained unresolved. We have attempted to incorporate a PEP

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Figure 1 A PEP film transducer (40 × 15 mm) alongside an old 50p piece.

Figure 2 Output from a PEP film transducer (mounted in a standard face mask on a spontaneously breathing subject with a normal respiratory rate).

transducer into a respiratory monitor and demonstrate its efficacy in a laboratory situation.

Laboratory evaluation of a PEP film transducer

MATERIALS

The PEP used was the polarised fluoropolymer, polyvinylidene fluoride (PVDF). This material exhibits a high pyroelectric constant [$30 \times 10^{-6} \text{ C}/(\text{m}^2\text{K})$] and very wide band electronic characteristics ($\sim\text{DC}$ to 2 GHz). Its infrared absorption spectrum peaks in the 7–20 μm wavelengths, which corresponds to heat emission from the human body. PVDF is resistant to moisture (<0.02% moisture absorption) and most chemicals. It is conformable to complex mouldings and can be fixed in place with standard adhesives.

A small piece of PEP film was found to be adequate as a transducer (fig 1). It was mounted inside a standard oxygen face mask. At this stage, no attempt was made to optimise the transducer design.

SIGNAL PROCESSING

The temperature differential between inspired and expired gas generates an open circuit output voltage across the transducer of typically $\sim 250 \text{ mV}$. To obtain the specimen trace shown in fig 2, a variable gain charge amplifier was used to scale the signal for acquisition by an A-D converter, sampling at a frequency of 2 kHz and operating under control of a software interface developed by the authors. A simple first order low pass filter was used to band limit the signal to provide a clean trace. The signal

was converted with 12 bit resolution, level shifted, and scaled to provide amplitude values within a range of 0–10 volts.

OUTPUT

The amplified output of the system described above (on a subject with a normal respiratory pattern) is shown in fig 2. The Y axis is in volts (10 volts full scale). The X axis is labelled in ms to reflect the sampling rate. Similar traces were obtained with other normal subjects.

Discussion

The PEP film transducer provides a respiratory tracing which is equal in sensitivity and response times to the output from a capnograph. The film is easily attached to the inside of a standard face mask and, in this non-clinical trial, was not disturbed by the flow of oxygen. As the transducer is self exciting, no power supply is necessary and the wire to the monitor can be led out along the oxygen tubing. Only a small piece of the film is required and this is so cheap (£0.50) as to be disposable with its integral mask. (The cost of a typical oxygen mask plus tubing is between £0.97 and £1.62.) The transducer can be amplified and configured to provide one channel of a multichannel monitor (perhaps interchangeably with a capnograph) or a second channel on a pulse oximeter.

In the laboratory, the PEP transducer performs well and appears to have many desirable features (table 1). If these advantages are maintained in a clinical setting, PEP based systems will compare favourably with both capnography and transthoracic impedance measurement as a means of monitoring respiration in the non-intubated patient (table 2).

Summary

Respiratory rate should be measured in all patients who are suffering from: acute illness; major injury; and the effects of sedation or general anaesthesia.

Capnography is the ideal method in those patients who have an endotracheal tube in situ. For patients who are not intubated, the introduction of PEP films has provided the material to make cheap and reliable respiratory transducers for use in face masks—a new answer to a very old problem.

Table 1 Advantages of the PEP film respiratory monitor

- Ideal for the non-intubated patient
- High quality output, unaffected by movement etc
- Fast response time
- Suitable as an apnoea monitor
- Cheap (disposable)
- Easy to use
- Self exciting
- High mechanical strength—damage and impact resistant

Table 2 Comparison of three methods of measuring respiratory rate

Transducer type	Suitable for non-intubated patient	Self exciting	Transient response	Time to show apnoea
PEP film	Yes	Yes	Rapid	One breath
Capnograph	No	No	Rapid	One breath
Impedance	Yes	No	Slow	>10 seconds

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