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# Monitoring in ICU - ECG, pulse oximetry and capnography

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**Summary**

Monitoring serves an important role in ICU as an adjunct to clinical evaluation. It is important that all staff are familiar with their equipment in order to use it safely and to the maximum benefit of the patient. In particular, the settings of the alarms must be tailored to each patient, with consideration to their age, weight and pathology.

## INTRODUCTION

In the intensive care unit (ICU), monitoring a patient's physiological parameters is an important part of their overall care package. Monitoring alerts you to any deterioration in a patient's condition and also helps you to asses their response to treatment. In this article we will consider three of the most commonly used electronic monitoring systems - electrocardiogram (ECG), pulse oximetry ($SaO_2$) and capnography. While these monitoring systems are important and useful, it should be remembered that they are always an addition to, rather than a replacement for, good clinical monitoring of heart rate, blood pressure, capillary refill time, respiratory rate, neurological status and urine output.

## WHAT ARE THE BENEFITS OF MONITORING?

ECG, $SaO_2$ and $CO_2$ monitoring systems require a source of power and usually additional 'consumables' such as the pulse oximetry probe or the D-fend water trap of the capnograph. They also require technical expertise for maintenance and repair. These aspects all make them potentially problematic in a low resource environment.

However the benefits include:

- **Additional clinical information**. ECG, $SaO_2$ and $CO_2$ give very useful information about your patient's cardiorespiratory function. This information is continuous and in 'real time' and so is especially useful in critically ill patients.
- **Non-invasive**. These monitors are non-invasive, and so are well tolerated.
- **Early warning system**. The monitor's alarm systems can be adjusted to detect deviation of parameters from acceptable levels, thus providing a prompt warning of any change in the patient's condition. Careful attention to the trends of these deviations will alert you to early signs of clinical deterioration.

The following section considers each monitoring system in turn, assessing what it can, and what it can't, tell you. The physics behind each type of monitor is not described, but can be found in previous editions of *Update in Anaesthesia*.[1-4]

## PULSE OXIMETRY ($SaO_2$)

If allowed only one form of monitoring, many anaesthetists would choose a pulse oximeter, reflecting how useful and informative this equipment can be. Most pulse oximeters are stand-alone units, usually battery-powered, but it may also be incorporated as part of a larger multipurpose monitor. It consists of a sensor probe, usually placed on the patient's finger, and a screen to display measured values.

### What can it tell you?

The most important information available from this monitor is the arterial blood oxygen saturation ($SaO_2$), which is given as a percentage. In a normal person breathing air, a value of 96-100% is normal. Note that in smokers and those with chronic lung disease the value is likely to be slightly lower, around 92-95%. Critically ill patients, particularly with a primary (e.g. pneumonia) or secondary (e.g. acute respiratory distress syndrome) lung disease will have impaired gas exchange and low oxygen saturations. The target level of saturation, achieved by administration of oxygen and ventilation, should be set with reference to their usual respiratory status. For example it is reasonable to aim for an $SaO_2$ of 88% in a patient with underlying chronic lung disease with an intercurrent infection.

Most $SaO_2$ monitors display a value for the heart rate and emit an audible tone in time with the heart beat. The pitch of the pulse tone varies as the $SaO_2$ level changes; it is difficult to guess the $SaO_2$ when you hear the tone in isolation, but a change in the pitch of the tone alerts you to look at the monitor. A pulse waveform is also included on the screen of some monitors - this gives information about the quality of the signal and indicates whether a low recording is likely to be genuine. In general, if a good signal is received, this indicates that perfusion to the patient's extremities is good. This also has specific role where the perfusion of a limb is at risk, for example following trauma or vascular surgery. A weak or absent signal, should alert you to assess the patients perfusion and blood pressure. Be aware that the signal will transiently disappear if the blood pressure cuff inflates on that arm.

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### What can't it tell you?

The $SaO_2$ only tells you part of the picture regarding oxygen delivery to the tissues, as this is also dictated by the haemoglobin level and the cardiac output. A patient with a hemoglobin level of $3.5g.dL^{-1}$ may have a $SaO_2$ of 100%, but have poor oxygen content in their blood and therefore low oxygen delivery to the tissues.

The $SaO_2$ value is determined by the effectiveness of both ventilation (i.e. the pump function of the lungs) and gas exchange across the alveolar-capillary membrane. However ineffective ventilation (for example, due to airway obstruction, opioid excess or neuromuscular weakness), causes type 2 respiratory failure, in which $CO_2$ accumulates. Pulse oximetry gives no indication of the arterial $CO_2$ level - a drowsy patient may have a reassuringly normal $SaO_2$ level if oxygen is being administered, but may have severe respiratory acidosis with a $PaCO_2$ over 10kPa and be close to cardiovascular collapse.

### Tips for successful use

Bright or fluorescent ambient light causes interference with signal detection, as can bright sunshine. The effects of external light can be minimized by covering the hand and probe with a dark material.

Patient movement can lead to artifact on the trace and inaccurate measurements - this is a particular problem with combative or agitated patients. If transferring a patient on an uneven road, taping the probe to the finger so that it moves 'with the limb' may help.

Different types of probe are available and if you have a choice, use one that is appropriate for your circumstances. All probes work in the same way; they are just designed to fit different sized patients and different parts of the body. Smaller ear probes are available as well as special probes for children. If no paediatric probe is available, an adult finger probe can be placed around a small child's hand or foot. Paediatric probes often come as single use stickers designed to go around a baby's hand or foot - when supplies are short these can be re-used after wiping gently with a cleaning swab, as long as they are not soiled. These probes will also fit well onto an adult's finger and do not fall off during transfers.

In a cold or shocked patient try placing the probe on a more central site. A finger probe can be clipped inside the patient's mouth to detect through their cheek. Alternatives are the nose or earlobe. A small ear probe can also be placed onto the cheek, the lip or onto a nostril.

## ELECTROCARDIOGRAM (ECG) MONITORING

ECG monitoring in ICU usually involves display of one lead - lead 2 - and measures the electrical activity of the heart along its long axis from right to left. Three electrodes are required for this - one on the right shoulder (usually red), one on the left shoulder (usually yellow) and one placed on the left side of the chest (usually green). Lead 2 is felt to detect most arrhythmias, which is the main role of ECG monitoring in the ICU setting.

### What can it tell you?

The heart rate is calculated by the monitor by averaging the number of complexes over a set period of time. If the patient has an irregular rhythm such as atrial fibrillation the rate is calculated most accurately if the calculation period is set at the longest available.

Arrhythmias are usually diagnosed by setting the alarm limits at a high and low limit, to detect tachy- and bradyarrhthmias. The default alarm settings are usually appropriate for a healthy adult undergoing anaesthesia, but may be inappropriate for critically ill adults or for young children. An adult with sepsis may have a heart rate of 120 per minute, which will be continuously above the default 'high heart rate' setting. The alarms can be adjusted manually to levels that would represent a clinically significant deviation from their current reading. Some monitors allow you to set the upper and lower alarm limits at 10% above and below the current measured value.

Some more advanced modules are able to recognize patterns and diagnose arrhythmias, however it is often down to the clinician to identify the nature of the arrhythmia (artifact due to movement or shivering is commonly interpreted as ventricular fibrillation). It is useful to use ECG and pulse oximetry in conjunction; onset of a broad complex tachycardia with loss of the pulse oximetry waveform indicates pulseless ventricular tachycardia (VT), a medical emergency.

It is often useful to print a rhythm strip on a piece of paper in order to study the rhythm more closely (e.g. looking for P-waves). It is also usually possible to 'pause' the screen to allow further analysis.

Be aware that some ECG signals are misread by the monitor, for example large T-waves may be counted as separate QRS complexes, doubling the measured rate. Again this can be resolved by comparing to the waveform and heart rate of the pulse oximeter. Multi-channel monitors that combine ECG, pulse oximetry (and invasive arterial blood pressure) usually default to show the heart rate from the ECG reading, but this can be changed to read from a different channel.

### What can't it tell you?

When a patient develops myocardial ischaemia, a single lead ECG may show morphology changes if the ischaemia happens to be in the area of the heart that corresponds to the single lead position. Otherwise it will be missed. You should request a full 12-lead ECG to assess all areas of the myocardium if you suspect myocardial ischaemia. A normal ECG trace does not always indicate a well patient; in the case of a pulseless electrical activity (PEA, formerly electro-mechanical dissociation) cardiac arrest, the patient has no cardiac output despite the fact that the ECG may be displaying normal sinus rhythm. Always check that what the monitor tells you corresponds with your patient's clinical appearance.

### Tips for successful use

Poor quality ECG monitoring can be due to poor contact between the electrodes and sweaty or dirty skin. Clean the skin thoroughly and allow it to dry completely before applying electrodes. If a patient is shivering or moving around then interference on the screen may give the appearance of an arrhythmia.

If you do not have any ECG sticker type electrodes, you can improvise by using a small piece of saline soaked gauze to couple the ECG lead to the skin.

## CAPNOGRAPHY ($CO_2$) MONITORING

There are various types of $CO_2$ monitoring available but most systems consist of a connector, placed in series with the patient's breathing

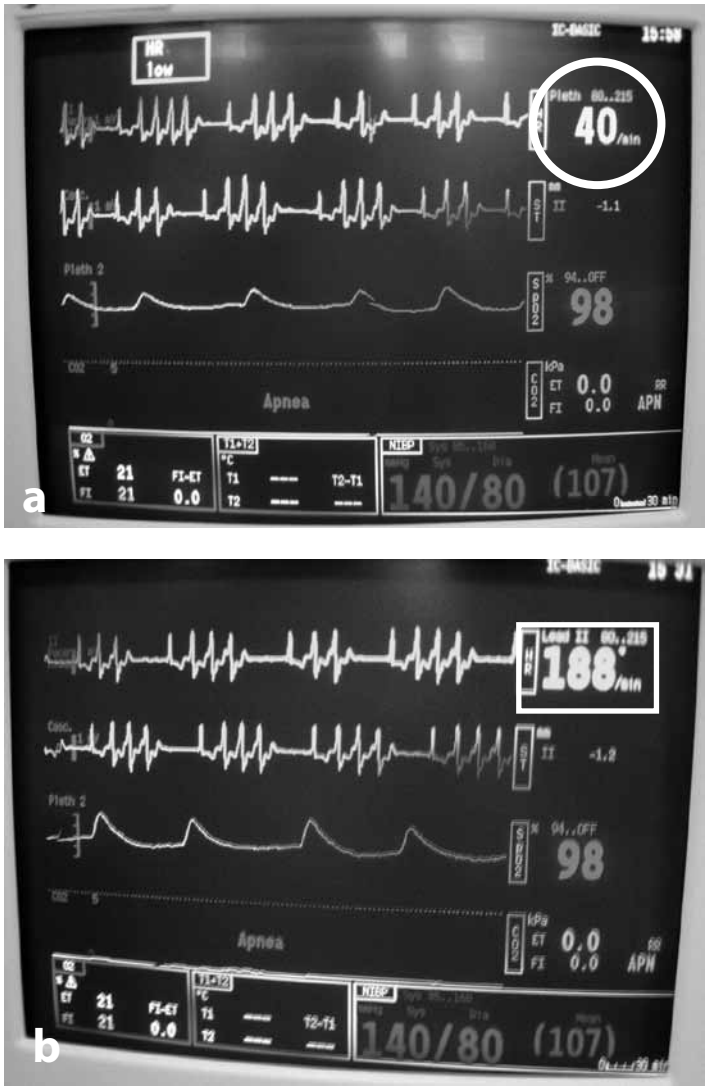



**Figure 1.** *Monitoring screens for a patient who has sinus beats followed by couplets and triplets of pulseless ectopic beats. In (a) the heart rate source (circled) is the pulse oximeter, correctly reading the effective pulse as 40bpm. In (b) the ECG has been selected as the heart rate source, recording a rate of 188 per minute (square), that corresponds to the number of ECG complexes, whether they generate an effective cardiac output or not. Either of these selections can be misleading if the ECG or pulse oximetry monitoring is viewed in isolation.*

system that is attached, via a sampling line, to a monitor. The monitor analyses the gas and the values are displayed on a screen. To get the most accurate reading, the connector in the breathing system should be placed as close as possible to the patient's mouth. If it is placed distant from the patient's mouth, falsely low readings result, as alveolar gas is diluted with fresh gas from the circuit tubing.

### What can it tell you?

$CO_2$ monitoring systems can tell you three important things:

1. Whether $CO_2$ is being detected in the patient's expired gas or not,
2. The partial pressure of $CO_2$ (capnometry),
3. It provides a continuous $CO_2$ waveform plotted against time (capnography).

More basic systems do not give a waveform but are nonetheless very useful.

*Is $CO_2$ present in the patient's expired gas?*

This information alerts you to a serious problem with the patient. If there is no $CO_2$ detected, either:

- the patient is not being ventilated e.g. displaced endotracheal tube, circuit disconnection, or
- no $CO_2$ is being delivered to the lungs because circulation has ceased (cardiac arrest).

Both of these situations obviously need urgent attention.

Where available it is mandatory to have capnography present during induction and intubation of the critically ill, in order to rapidly confirm tracheal intubation, or to identify incorrect placement.

*How much $CO_2$ is present?*

The $CO_2$ reading at end-expiration (end-tidal, ET-$CO_2$) most accurately represents the $PaCO_2$, but note that the ET-$CO_2$ level is generally 0.5kPa lower than the $PaCO_2$. However this difference is not predictable in all patients, particularly those with major mismatches between perfusion and ventilation of their lungs. For some conditions, such as acute head injury, the $PaCO_2$ level is critical and so, where available, arterial sampling is useful. Even if performed very irregularly, it can be used to quantify the end-tidal:arterial $CO_2$ difference, so that capnography can be used more effectively to alter the patient's ventilator settings.

$CO_2$ output from the lungs is dictated by:

1. The rate at which $CO_2$ is produced and transported to the lungs (i.e. the patient's metabolic rate and cardiac output).
2. The patient's minute ventilation (MV) - this is the volume of gas moving into the lungs per minute and is the product of respiratory rate and tidal volume. The relationship is inverse, i.e. if the MV rises the $PaCO_2$ falls.

The monitor will give you a number in mmHg, kPa or percentage, with the percentage very close numerically to the kPa value, since atmospheric pressure is 101kPa. As a guide, 4-6kPa or 35-45mmHg are normal values in healthy non-smokers. Often the trend in $CO_2$ and the rate of rise or fall is more important than the actual value. For example, a rising $CO_2$ in a ventilated patient could indicate that their lungs are becoming less compliant, as they develop ARDS, or that their metabolic rate has increased, as they develop sepsis.

### The capnography waveform

In order to recognize abnormal waveform patterns a normal waveform for a circle system is shown in Figure 2.

### What can't it tell you?

All of the scenarios described above are guides to be assessed in line with clinical review of the patient. Sudden loss of the capnograph trace may represent equipment failure or blockage of the sample tubing with water vapour. For this reason the sample tubing should always be on the ventilator side of a heat and moisture exchanger.

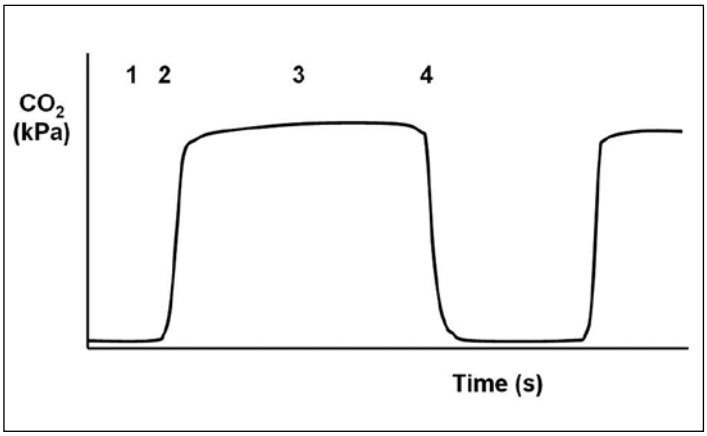



**Figure 2.** *Normal capnography trace; Phase 4 corresponds to the onset of inspiration, Phase 1 corresponds to inspiration. During this phase the waveform should return to zero. If it doesn't, this indicates an element of rebreathing; Phase 2 corresponds to the onset of expiration. As alveolar gas containing $CO_2$ mixes with dead space gas the level of $CO_2$ in the breathing circuit rises. Phase 3 is the plateau phase and corresponds to expiration of pure alveolar gas. The $CO_2$ value at the end this phase is the end tidal $CO_2$ (ET-$CO_2$) and is the value displayed by the monitor. It is normal to have a very slight upslope during the plateau phase. The level of $CO_2$ detected in the circuit drops as fresh gas is inspired.*

The following are examples of abnormal traces that you might see on the ICU:

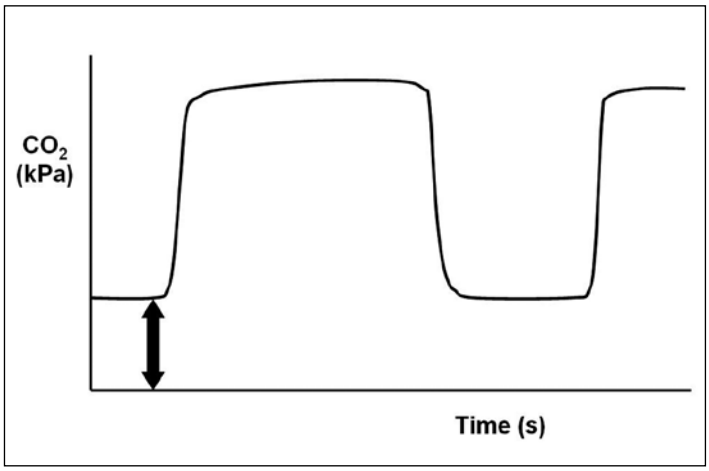



**Figure 3.** *Rebreathing - the baseline does not return to zero (arrow) and may increase over time. This is commonly caused by exhausted soda lime or in inadequate gas flows for the breathing circuit in use.*

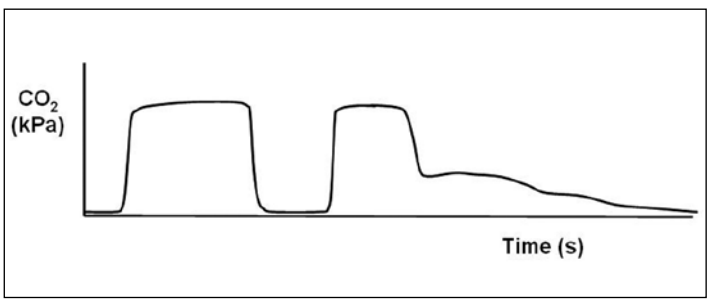



**Figure 4.** *Sudden decrease in $CO_2$ waveform. This may represent an interruption in ventilation e.g. breathing circuit disconnection or a sudden decrease in cardiac output e.g. cardiac arrest.*

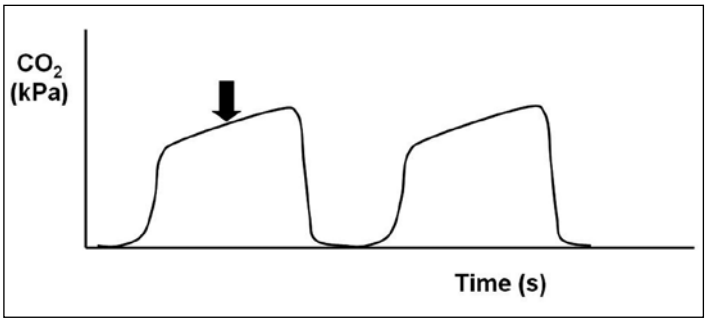
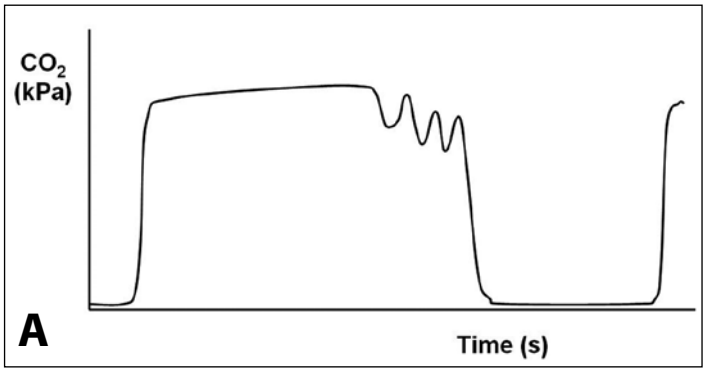



**Figure 5.** *Up-sloping phase 3. An upslope to the phase 3 plateau (arrow) is often in seen in patients with a prolonged expiratory time e.g. in lung disease such as chronic obstructive pulmonary disease (COPD). A longer time for expiration may be required if the patient is being mechanically ventilated.*



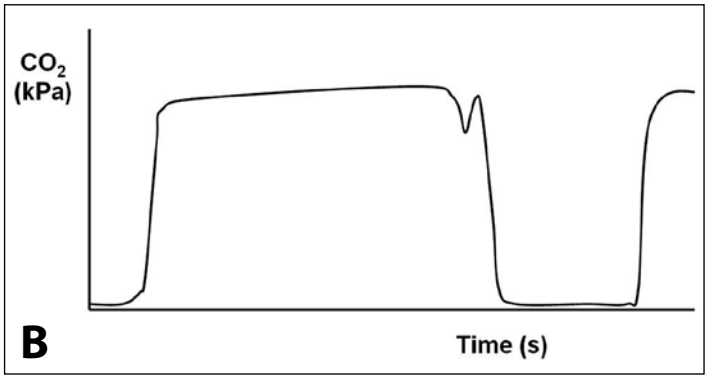




**Figure 6**. *Superimposed waveform. Sometimes you might see smaller waves or oscillations on the normal $CO_2$ waveform. This might represent cardiac oscillations whereby a pressure wave from the heart is transmitted to the airway (A). Alternatively it might represent regular attempts by a patient to breathe over the top of mechanical ventilation (B) - as a 'cleft' in the $CO_2$ waveform.*

## SETTING ALARMS

A major factor in the effective use of monitors to alert nurses and clinicians to a change in the status of the patient, is the sensible use of the machine's alarm systems. Most monitors come with pre-programmed alarm settings, set by the manufacturer for an average adult patient. Typical settings are as follows (but may differ between manufacturers):

- $SaO_2$: Will alarm if less than or equal to 94%
- ET-$CO_2$: Will alarm if less than 4kPa or greater than 6kPa

- ECG: Will alarm if heart rate less than 60 or greater than 100 beat per minute. Some monitors will detect arrhythmias.

As you become more familiar with the patient you are treating you may decide to alter the alarm settings. For example, a fit young patient may have a normal heart rate of 40-50 and you will want to alter your alarm settings accordingly. If you do not do this, then the alarm will sound continuously, be repeatedly silenced and will loose its power to alert you to clinically important changes. As evidence of this, you may notice that the 'silence' or 'suspend' buttons on your monitors wear out well before the other buttons!

Beware of relying completely on the monitor alarms - someone may have re-set them to limits that are not appropriate to your patient, or even turned the alarm system off altogether.

## CONCLUSION

Using capnography, pulse oximetry and ECG monitoring can be an invaluable addition to treating a patient in the ICU setting, increasing safety and optimising treatment. Remember that all monitors are only as good as the person using them - think about what you are measuring, set your alarms appropriately and always use them in conjunction with clinical examination.

## FURTHER READING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