PULSE OXIMETRY

Pulse oximetry is a complex spectrophometric technique for the monitoring of arterial haemoglobin oxygen concentration. It has gained rapid acceptance, as despite its technical complexity, it is easy to apply, requires no user calibration, has a reasonable accuracy (+/- 1-2%) and a very low morbidity. However it is most important to remember that it does not replace arterial blood gas estimation, even of oxygen.

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Volume 5 Issue 2 1999

JNN JOURNAL OF neonatal NURSING

As everyone knows, the colour of blood varies with the amount of oxygen it is carrying. The absorption spectra of fully oxygenated haemoglobin and haemoglobin carrying no oxygen are shown in Fig 1. Pulse oximetry uses two wavelengths as marked in Fig 1: 660nm (red) and 940nm (near infrared). By comparing the absorption of the energy of these two wavelengths when they are passed through part of the periphery such as a finger or toe, it is possible to calculate the state of oxygenation of haemoglobin. Unfortunately there are many other absorbents of energy, as light passes through the tissues, not least the blood in the veins.

In order that the ratio of absorption relates only to the situation in the arteries, the constant part of the absorption waveform is electronically removed and the ratio of the variable parts of these signals is compared. This technique relies on the absorption by the tissues and the venous blood being non-pulsatile. Here lies the first possibility for error with neonates and small children. There is a greater possibility of the veins exhibiting pulsatility due to the shorter capillaries and arterio-venous shunts between arterioles and the venules than in larger children and adults. Any other causes of the venous pulsatility such as congenital cardiac malformation will similarly lead to a lower indicated SpO_2 than the true case.

The ratio of the red to infrared pulsatile signals is then applied to a look-up table stored in the device's memory which converts the ratio to the saturation value. Complex averaging techniques are used to eliminate artefacts.

The reliance upon pulsatility does have one advantage in that if the pulsatlity ceases or falls below a critical level as with circulatory failure, an immediate alarm is sounded as the device can no longer calculate SpO_2.

Accuracy and calibration

Saturation measured by pulse oximetry should not be compared with the saturation value indicated by blood gas analysis (BGA). BGA measures PO_2, PCO_2 and the pH of a sample of blood. These values are the only genuine measurement made and all other values including SO_2 are calculated making many assumptions. Pulse oximetry may be reasonably compared with CO-Oximetry. This technique uses spectrophotometry on discrete blood samples; the other main differences are that more than two wavelengths are used (up to 13 in the most modern CO-Oximeters) and they are generally in the visible wavelength range.

As many wavelengths are used the CO-Oximeter is able to differentiate between adult haemoglobin, (HbA), fetal haemoglobin (HbF), carboxyhaemoglobin and methaemoglobin. CO-Oximetry should be used to check the

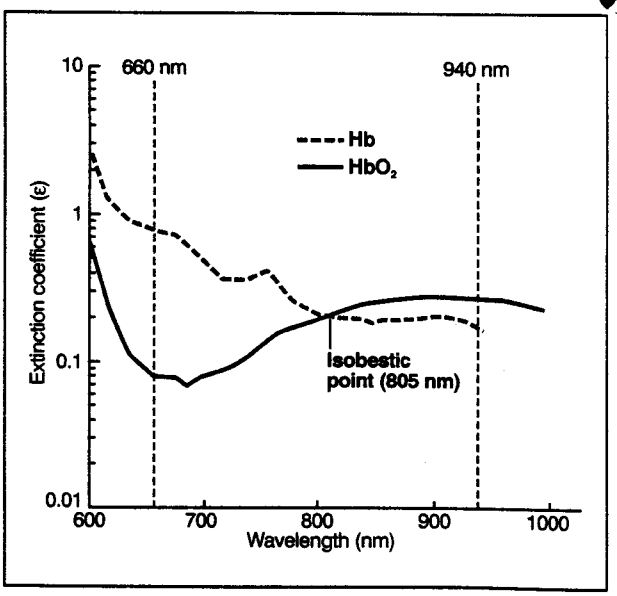

Fig 1 Absorption spectra of oxygenated and deoxygenated haemoglobin, showing the two most commonly used wavelengths.

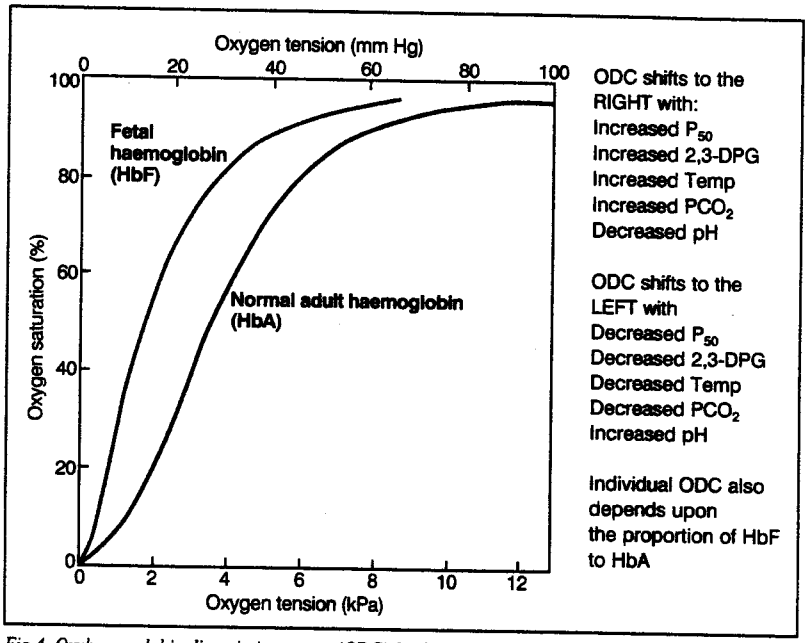

Fig 4. Oxyhaemoglobin dissociation curves (ODC) for fetal and adult haemoglobin.

assessing arterial haemoglobin oxygen saturation which, at first sight, would appear to be a simple replacement for arterial blood gas analysis with little or no morbidity. Pulse oximetry does have the advantages of easy application, no user calibration, low capital cost, very low morbidity and a continuous indication of SaO_2 or rather SpO_2 which means "SaO_2 as measured with a pulse oximeter". However, although an SpO_2 of >95% indicates satisfactory oxygenation of arterial blood, it does not provide an indication of PaO_2, the partial pressure of oxygen in the arterial blood.

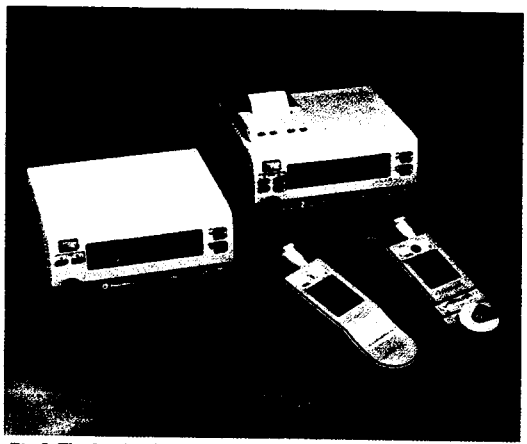

Fig 5. The family of Datex-Ohmeda Oximeters.

It is important to understand the Oxyhaemoglobin Dissociation Curve, ODC, which is the relationship between SpO_2 and PaO_2. The ODC in Fig. 4 shows the relationship between SpO_2 and PaO_2 for HbA, HbF and also the factors that may shift both ODC's to the left or right, changing this relationship. In the case of the neonate even small changes in ventilator control settings may cause fairly rapid shifts in the ODC by changing the arterial carbon dioxide and pH. Slight hyperventilation shifts the ODC to the left, whereas hypoventilation shifts it to the right, changing the relationship between SpO_2 and PaO_2.

Change in body temperature also shifts the ODC. There is also inter-individual variation. The actual ODC in practice therefore not only depends upon the factors which may cause a shift but also the proportion of HbF to HbA, a ratio which changes in favour of HbA as the neonate matures. Further, the relationship between SpO2 and PaO2 is less accurate above 95% due to the 'flatness' of the ODC above 95%. Pulse oximetry was developed to warn against arterial hypoxaemia *NOT* hyperoxaemia.

There have been a number of papers written suggesting that pulse oximetry may be used to protect against retrolental fibroplasia. The authors show a lack of understanding of the factors that may affect the relationship between SpO_2 and PaO_2. It is dangerous to attempt to protect the neonate from retrolental fibroplasia by relying upon limiting the SpO_2 to a certain maximum value as, for example, a baby with an SpO_2 of 95%, who is being mildly hyperventilated, may have a PaO_2 of less than 6kPa. Pulse oximetry is a very sensitive monitor of haemoglobin oxygen desaturation but should never be used to prevent hyperoxia as inadvertent hypoxia may occur if an upper limit of less than 97% is used.

Abbreviations

SO_2	The percentage oxygen saturation of the haemoglobin in blood
SaO_2	The percentage oxygen saturation of the haemoglobin in arterial blood
SpO_2	The percentage oxygen saturation of the haemoglobin in arterial blood as measured by pulse oximetry
PO_2	The partial pressure of oxygen in blood
PaO_2	The partial pressure of oxygen in arterial blood
$PaCO_2$	The partial pressure of carbon dioxide in arterial blood

Further Reading

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Whyte R.K., Jangard K.A., Dooley K.C. (1995) From oxygen content to pulse oximetry: Completing the picture in the newborn. *Acta Anaesthesiologica Scandinavica*, **39** Supp 107: 95-100.

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accuracy of pulse oximetry and to detect any dyshaemoglobins that may interfere with its accuracy.

Limitations of pulse oximetry

As the pulsatility of the energy absorption is of the order of 1% of the total tissue absorption, any mechanical movement of the extremity to which the probe is attached causes interference that may cause the technique to fail. There are a number of other less common problems, which may upset the technique in a 'safe' manner in that the failure is obvious, and often causes an alarm to sound. Of more concern are conditions which affect the accuracy of pulse oximetry but leave the observer with the impression that the indicated SpO_2 is accurate.

Carboxyhaemoglobin (COHb), even in non-fatal concentrations, makes pulse oximetry overread; for every 1% COHb the SpO_2 value indicated will be approximately 1% higher than the true SaO_2. Methaemoglobin affects pulse oximetry in a different way: increasing methaemoglobinaemia makes the indicated SpO_2 value tend towards 85%. Although methaemoglobinaemia may be congenital, it may be induced by industrial chemicals and dyes and also certain drugs, including antimalarials, local anaesthetic agents, nitrates/nitrites and sulphonamides to name but a few. There are also a number of rare congenital haemoglobinopathies, which upset the accuracy of pulse oximetry.

Hyperbilirubinaemia does not effect the accuracy of pulse oximetry but may affect the accuracy of older CO-oximeters.

The reason for this discrepancy is that CO-oximeters use wavelengths of light in the visible part of the spectrum, where bilirubin may absorb energy. Bilirubin does not absorb energy of the wavelengths used by pulse oximetry.

Application of the probe

Accuracy and safety with babies and small children are only achieved if the correct type of probe for the size of the child is applied in the correct manner. Each manufacturer produces specialised probes for neonates (Fig 2), babies

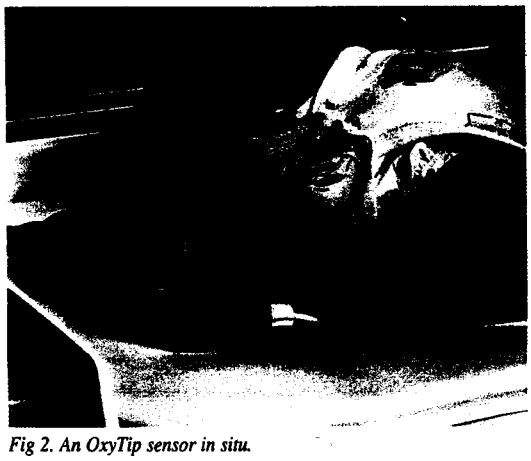

Fig 2. An OxyTip sensor in situ.

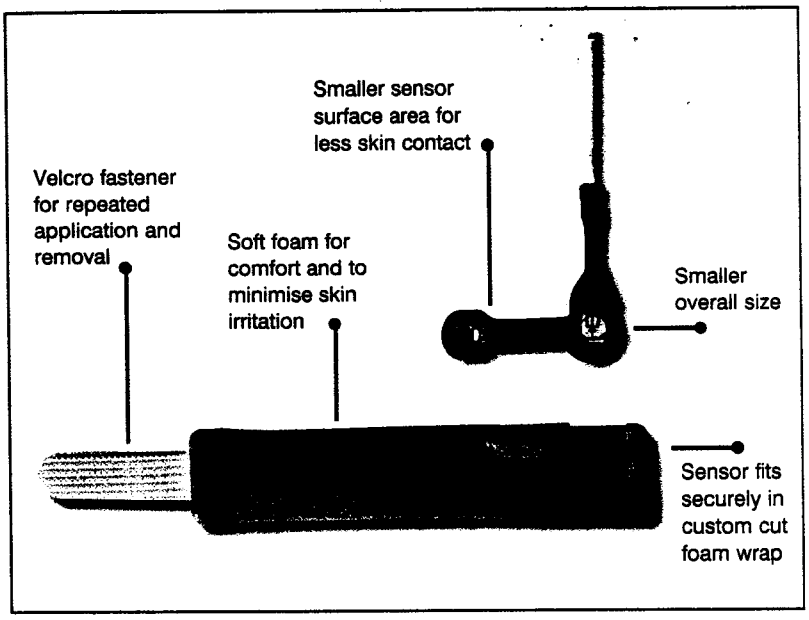

Fig 3. The Ohmeda Preemie OxyTip® sensor with the TenderTouch Wrap System is specially designed for premature babies under 1500 grams.

and small children. It is important that the correct type of probe is used appropriate to the size of the patient and that the manufacturer's instructions are closley adhered to (Fig 3).

Some have found that a certain manufacturer's adult probe which is made from synthetic rubber appears to operate satisfactorily on babies when it is applied in the reverse manner. However, not only does this particular manufacturer state thay this should not be done, but also pressure damage may occur to the delicate digits of the baby. Furthermore results obtained using the probe in this way are inaccurate as the two energy sources are too far apart for the energy to pass through equal thickness of tissue in the neonatal situation. Also the energy required for pulse oximetry in adults is more intense than with neonates with the greater risk of thermal injury.

It is always tempting to ensure the probe's fixation with extra adhesive tape. However not only will the accuracy be affected but also there is a risk of pressure damage or even thermal damage to the extremity.

Thermal damage from a pulse oximeter probe is rare but may occur if the probe is applied too tightly as the capillary blood flow beneath the energy sources may be reduced thus allowing heat energy to accumulate. However this risk is extremely small compared to transcutaneous gas monitoring.

What does pulse oximetry indicate?

Probably the one most important factor in the safe use of pulse oximetry in the neonate is an understanding of the relationship between arterial haemoglobin oxygen saturation and the partial pressure of oxygen in arterial blood. Pulse oximetry is a non-invasive method of