

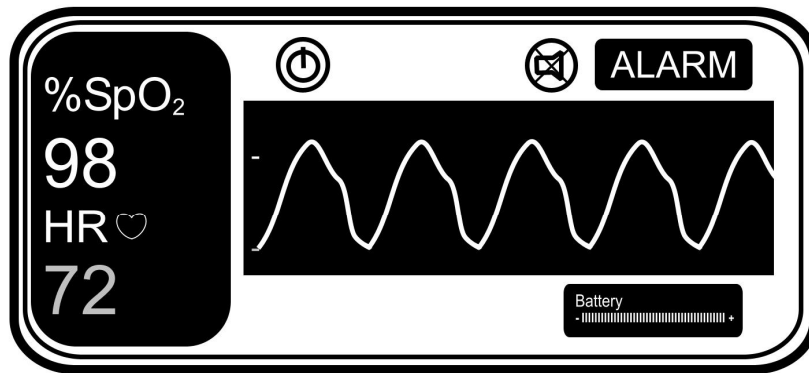


**World Health
Organization**

Patient Safety

A World Alliance for Safer Health Care

Pulse Oximetry Training Manual



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THE WHO PULSE OXIMETRY TRAINING MANUAL

Welcome to the World Health Organization pulse oximeter training manual. WHO has recently introduced the WHO Surgical Safety Checklist as part of the Safe Surgery Saves Lives initiative. Measures to improve anaesthesia safety are integral to the programme. In many countries pulse oximetry is mandatory for monitoring patients during anaesthesia.

Although pulse oximetry is a simple and reliable technology that can detect low levels of oxygen in the blood, it is only effective if the anaesthesia provider understands how an oximeter works and what to do when hypoxia is detected. This manual describes a simple plan to respond to this situation, and explains how oximeters work and how to use them.

The manual contains essential information for all anaesthesia providers who are not experienced in using pulse oximetry and would be useful reading for all members of the theatre team.

The content of this manual can be studied on its own or can be taught in a classroom. Additional learning materials about pulse oximetry and information on the WHO Surgical Safety Checklist can be freely obtained at http://www.who.int/patientsafety/safesurgery/pulse_oximetry/en/index.html and at <http://www.who.int/patientsafety/safesurgery/en/index.html> respectively. The material may be freely distributed for educational purposes.

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GLOSSARY OF TERMS

| | |
|---|--|
| Anaphylaxis | A severe life threatening allergic reaction to a drug or other substance such as latex in surgical gloves |
| Arrhythmia | An abnormal heart rhythm |
| Atelectasis | Partial or total collapse of a lung or segment of a lung which has been previously expanded |
| Bradycardia | A heart rate that is too slow for the patient. Adults less than 60 beats / min; children according to age – see page 9 of this manual |
| Capnograph | A monitor that detects the amount of carbon dioxide in each breath |
| Cyanosis | Dusky blue appearance of the skin, tongue or mucous membranes due to a low level of oxygenated haemoglobin in blood vessels near the skin surface |
| Desaturated haemoglobin | Haemoglobin without attached oxygen |
| Hypotension | Low blood pressure |
| Hypothermia | Low body temperature (less than 36°C) |
| Hypoventilation | Breathing at a rate and/or depth that is less than required |
| Hypovolaemia | Reduced blood volume |
| Hypoxia | Abnormally low levels of oxygen in the body |
| Microprocessor | A mini-computer that can calculate readings of pulse rate and peripheral haemoglobin saturation from signals detected by the probe |
| Oesophageal intubation | A tracheal tube that is incorrectly inserted into the oesophagus |
| Oximeter / Oximetry Pulse oximeter /Pulse oximetry | A device that can detect a pulsatile signal in an extremity such as the finger or toe and can calculate the amount of oxygenated haemoglobin and the pulse rate |
| Pneumothorax | Lung collapse caused by air leaking from the lung, usually following trauma. Air enters the space outside the lung (pleural space) and stops the lung from expanding (also see Tension pneumothorax) |
| Pyrexia | Raised body temperature (greater than 37°C) |
| Tension pneumothorax | In a tension pneumothorax, the pressure in the pleural space is very high, the patient has severe breathing difficulties and distortion of the heart may cause cardiac arrest |
| Vasopressors | Drugs such as adrenaline, ephedrine or phenylephrine that raise the blood pressure by causing constriction of blood vessels or increased cardiac output |

UNDERSTANDING THE PHYSIOLOGY OF OXYGEN TRANSPORT

PULSE OXIMETER QUIZ 1

Before reading the manual, we would like you to assess your knowledge about pulse oximetry. The correct answers are in the next section.

1. How is oxygen transported from the atmosphere to the tissues?
2. What is the normal oxygen saturation in arterial blood?
3. What is preoxygenation?
4. A patient undergoing general anaesthesia for hernia repair has an oxygen saturation of 82% during surgery. Is this reading high or low? Is any action required?

OXYGEN

Human beings depend on oxygen for life. All organs require oxygen for metabolism but the brain and heart are particularly sensitive to a lack of oxygen. Shortage of oxygen in the body is called **hypoxia**. A serious shortage of oxygen for a few minutes is fatal.

During anaesthesia, patients' airways may become obstructed, their breathing may become depressed, their circulation may be affected by blood loss or an abnormal heart rhythm or the anaesthetic equipment may develop a problem such as an accidental disconnection or obstruction of the breathing circuit. These factors can result in a reduction of oxygen delivery to the tissues which, if not managed correctly, could lead to injury or death. The earlier the anaesthesia provider detects a problem, the sooner it can be treated so that no harm comes to the patient.

OXYGEN TRANSPORT TO THE TISSUES

Oxygen is carried around the body attached to an iron-containing protein called haemoglobin, (Hb) contained in red blood cells. After oxygen is breathed into the lungs, it combines with the haemoglobin in red blood cells as they pass through the pulmonary capillaries. The heart pumps blood continuously around the body to deliver oxygen to the tissues.

There are five important things that must happen in order to deliver enough oxygen to the tissues:

- Oxygen must be breathed in (or inspired) from the air or anaesthesia circuit into the lungs.
- Oxygen must pass from the air spaces in the lung (called the alveoli) to the blood. This is called alveolar gas exchange.
- The blood must contain enough haemoglobin to carry sufficient oxygen to the tissues.
- The heart must be able to pump enough blood to the tissues to meet the patient's oxygen requirements.
- The volume of blood in the circulation must be adequate to ensure oxygenated blood is distributed to all the tissues.

HOW MUCH OXYGEN DOES THE BLOOD CARRY?

In a patient who is in good health:

- Each gram of haemoglobin combines with 1.34 ml of oxygen. Therefore, in blood with a normal haemoglobin concentration of 15g/dl, 100 ml of blood carries approximately 20 ml of oxygen combined with haemoglobin. In addition, a small quantity of oxygen is dissolved in the blood.
- The heart normally pumps approximately 5000 ml of blood per minute to the tissues in an average sized adult. This delivers about 1000 ml of oxygen to the tissues per minute.
- The cells in the tissues extract oxygen from the blood for metabolism, normally around 250ml of oxygen per minute. This means that if there is no oxygen being exchanged in the lung, there is only enough oxygen stored in the blood for around 3 minutes (only 75% of the oxygen carried by

the haemoglobin is available to the tissues).

- Breathing 100% oxygen prior to induction of anaesthesia (preoxygenation) increases the oxygen stores in the lungs. If a patient stops breathing and is not ventilated, the amount of oxygen in the lungs will rapidly diminish. If the patient has been given 100% oxygen to breathe for several minutes prior to induction of anaesthesia, the increased oxygen reservoir will supply much needed oxygen, adding potentially life-saving minutes. There are many situations where this may be important. One example is in the pregnant mother where the enlarged uterus reduces lung volume and the metabolic demands are increased by the foetus. Another example is in young children who have small lung volumes and high metabolic demands. They can use up oxygen very quickly and can sometimes be resistant to efforts to preoxygenate them.
- Anaemic patients have lower levels of haemoglobin and are therefore unable to carry as much oxygen in the blood. At a haemoglobin concentration of less than 6g/dl, delivery of oxygen to the tissues may become too low to meet the metabolic demands. Patients who suffer major blood loss during surgery and become acutely anaemic should be given 100% oxygen to breathe. This will increase the amount of dissolved oxygen in the blood and will improve tissue oxygen delivery by a small amount. Blood transfusion may be life saving.

WHAT IS OXYGEN SATURATION?

Red blood cells contain haemoglobin. One molecule of haemoglobin can carry up to four molecules of oxygen after which it is described as “saturated” with oxygen. If all the binding sites on the haemoglobin molecule are carrying oxygen, the haemoglobin is said to have a saturation of 100%. Most of the haemoglobin in blood combines with oxygen as it passes through the lungs. A healthy individual with normal lungs, breathing air at sea level, will have an arterial oxygen saturation of 95% – 100%. Extremes of altitude will affect these numbers. Venous blood that is collected from the tissues contains less oxygen and normally has a saturation of around 75%. (See appendix 1 for more details about this).

Arterial blood looks bright red whilst venous blood looks dark red. The difference in colour is due to the difference in haemoglobin saturation. When patients are well saturated, their tongues and lips appear pink in colour; when they are desaturated, they appear blue. This is called cyanosis. It can be difficult to see cyanosis clinically, particularly in a dark skinned patient. You may not notice this sign until the oxygen saturation is less than 90%. Detecting cyanosis is even more difficult in a poorly lit operating theatre.

Cyanosis is only visible when the deoxygenated haemoglobin concentration is greater than 5 g/dl. A severely anaemic patient may not appear cyanosed even when extremely hypoxic as there is very little haemoglobin circulating through the tissues.

During anaesthesia the oxygen saturation should always be 95 - 100%. If the oxygen saturation is 94% or lower, the patient is hypoxic and needs to be treated quickly. **A saturation of less than 90% is a clinical emergency.**

Learning point: It is difficult to detect cyanosis clinically until the saturation is <90%. A patient who is severely anaemic may not appear cyanosed, even if the oxygen saturation is very low.

KNOWING THE PULSE OXIMETER

PULSE OXIMETER QUIZ 2:

The correct answers are in the next section.

1. What two things does a pulse oximeter measure?
 2. What is displayed on a pulse oximeter screen?
 3. An oximeter probe has two parts. What are they?
-

WHAT DOES A PULSE OXIMETER MEASURE?

There are TWO numerical values obtained from the pulse oximeter monitor:

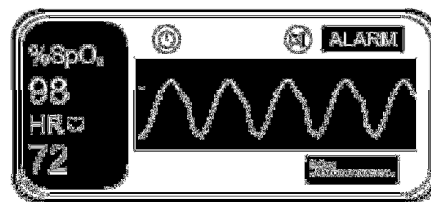
- **The oxygen saturation of haemoglobin in arterial blood.** The value of the oxygen saturation is given together with an audible signal that varies in pitch depending on the oxygen saturation. A falling pitch indicates falling oxygen saturation. Since the oximeter detects the saturation peripherally on a finger, toe or ear, the result is recorded as the peripheral oxygen saturation, described as SpO₂.
- **The pulse rate** in beats per minute, averaged over 5 to 20 seconds. Some oximeters display a pulse waveform or indicator that illustrates the strength of the pulse being detected. This display indicates how well the tissues are perfused. The signal strength falls if the circulation becomes inadequate.

Learning point: A pulse oximeter is an early-warning device.
A pulse oximeter continuously measures the level of oxygen saturation of haemoglobin in the arterial blood. It can detect hypoxia much sooner than the anaesthesia provider can see clinical signs of hypoxia such as cyanosis. This ability to provide an early warning has made the pulse oximeter essential for safe anaesthesia.

THE PULSE OXIMETER:

A pulse oximeter consists of the **monitor** containing the batteries and display, and the **probe** that senses the pulse.

This picture shows a pulse oximeter. The screen shows that the SpO₂ is 98% and the pulse rate is 72 beats per minute.



THE PULSE OXIMETER MONITOR

The monitor contains the microprocessor and display. The display shows the oxygen saturation, the pulse rate and the waveform detected by the sensor. The monitor is connected to the patient via the probe.

During use, the monitor updates its calculations regularly to give an immediate reading of oxygen saturation and pulse rate. The pulse indicator is continuously displayed to give information about the

circulation. The audible beep changes pitch with the value of oxygen saturation and is an important safety feature. The pitch drops as the saturation falls and rises as it recovers. This allows you to hear changes in the oxygen saturation immediately, without having to look at the monitor all the time.

The monitor is delicate. It is sensitive to rough handling and excessive heat and can be damaged by spilling fluids on it. The monitor can be cleaned by gently wiping with a damp cloth. When not in use, it should be connected to an electrical supply to ensure that the battery is fully charged.

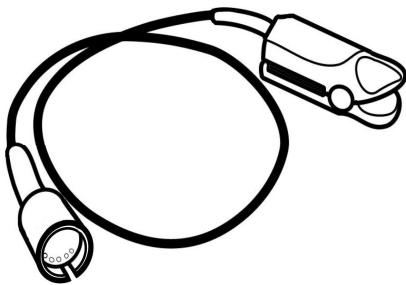
THE PULSE OXIMETER PROBE

The oximeter probe consists of two parts, the light emitting diodes (LEDs) and a light detector (called a photo-detector). Beams of light are shone through the tissues from one side of the probe to the other. The blood and tissues absorb some of the light emitted by the probe. The light absorbed by the blood varies with the oxygen saturation of haemoglobin. The photo-detector detects the light transmitted as the blood pulses through the tissues and the microprocessor calculates a value for the oxygen saturation (SpO_2).

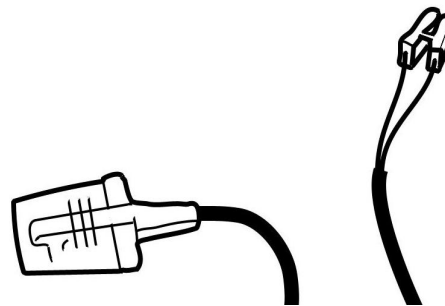
In order for the pulse oximeter to function, the probe must be placed where a pulse can be detected. The LEDs must face the light detector in order to detect the light as it passes through the tissues. The probe emits a red light when the machine is switched on; check that you can see this light to make sure the probe is working properly.

Probes are designed for use on the finger, toe or ear lobe. They are of different types as shown in the diagram. Hinged probes are the most popular, but are easily damaged. Rubber probes are the most robust. The wrap around design may constrict the blood flow through the finger if put on too tightly. Ear probes are lightweight and are useful in children or if the patient is very vasoconstricted. Small probes have been designed for children but an adult hinged probe may be used on the thumb or big toe of a child. For finger or toe probes, the manufacturer marks the correct orientation of the nail bed on the probe.

The oximeter probe is the most delicate part of a pulse oximeter and is easily damaged. Handle the probe carefully and never leave it in a place where it could be dropped on the floor. The probe connects to the oximeter using a connector with a series of very fine pins that can be easily damaged – see diagram. Always align the connector correctly before attempting to insert it into the monitor. Never pull the probe from the machine by pulling on the cable; always grasp the connector firmly between finger and thumb.



Hinged finger probe showing connector that can only be connected to the oximeter one way by aligning the gap on the probe connector with the corresponding notch on the machine.



Rubber finger probes and ear sensor

When not in use, the oximeter probe cable may be loosely coiled for storage or carrying, but should not be coiled too tightly as this will damage the wires inside the cable. The lens and detector should be kept clean. Use soapy water or an alcohol soaked swab to **gently** clean dust, dirt or blood from the probe.

Learning point: In order to get a satisfactory reading the probe must be emitting a red light and must be correctly positioned to detect pulsatile blood flow.

PRACTICAL USE OF THE PULSE OXIMETER

- Turn the pulse oximeter on: it will go through internal calibration and checks.
- Select the appropriate probe with particular attention to correct sizing and where it will go (usually finger, toe or ear). If used on a finger or toe, make sure the area is clean. Remove any nail varnish.
- Connect the probe to the pulse oximeter.
- Position the probe carefully; make sure it fits easily without being too loose or too tight.
- If possible, avoid the arm being used for blood pressure monitoring as cuff inflation will interrupt the pulse oximeter signal.
- Allow several seconds for the pulse oximeter to detect the pulse and calculate the oxygen saturation.
- Look for the displayed pulse indicator that shows that the machine has detected a pulse. Without a pulse signal, any readings are meaningless.
- Once the unit has detected a good pulse, the oxygen saturation and pulse rate will be displayed.
- Like all machines, oximeters may **occasionally** give a false reading - if in doubt, rely on your clinical judgement, rather than the machine.
- The function of the oximeter probe can be checked by placing it on your own finger.
- Adjust the volume of the audible pulse beep to a comfortable level for your theatre – never use on silent.
- **Always make sure the alarms are on.**

If no signal is obtained on the oximeter after the probe has been placed on a finger, check the following:

- Is the probe working and correctly positioned? Try another location.
- Does the patient have poor perfusion?
 - Check for low cardiac output especially due to hypovolemia, cardiac problems or septic shock. If hypotension is present, resuscitation of the patient is required immediately. The signal will improve when the clinical condition of the patient improves.
 - Check the temperature of the patient. If the patient or the limb is cold, gentle rubbing of the digit or ear lobe may restore a signal.

Tip: If you are uncertain that the probe is working properly, check it by testing it on your own finger.

WHAT DO THE ALARMS ON A PULSE OXIMETER TELL YOU?

Alarms alert the anaesthetist to clinical problems. The alarms are as follows:

- Low saturation emergency (hypoxia) i.e. SpO₂ <90%
- No pulse detected
- Low pulse rate
- High pulse rate

Low saturation alarm. The oxygen saturation in healthy patients of any age should be 95% or above.

Learning point: During anaesthesia the SpO₂ should be 95% or above. If SpO₂ is 94% or below, the patient must be assessed quickly to identify and treat the cause.

SpO₂ OF < 90% IS A CLINICAL EMERGENCY AND SHOULD BE TREATED URGENTLY.

'**No pulse detected**' alarm is commonly caused by the probe coming off the finger, but it may also be triggered if the patient is hypotensive, hypovolaemic, or has suffered a cardiac arrest. Check the probe site quickly and then assess the patient - ABC.

Pulse rate alarms are useful to let the anaesthetist know that the heart is beating too fast or too slow. However, alert anaesthetists will have already noticed the abnormal heart rate before the alarms sound. Children normally have higher heart rates than adults, but the same oxygen saturation – see table below.

| Age | Normal Heart Rate | Normal oxygen saturation (SpO ₂) |
|--|-----------------------------------|--|
| Newborn – 2 years 2-10 years 10 years -adult | 100 - 180 60 - 140 50 - 100 | All patients should have an SpO ₂ of 95% or above during anaesthesia or during recovery from anaesthesia* |

* Exception: premature babies receiving oxygen therapy in the neonatal ICU should have an SpO₂ between 89-94% to avoid toxicity to the retina. During surgery the oxygen saturation of premature babies should be maintained at >95%, as with all other patients.

Light anaesthesia, inadequate pain relief, atropine, ketamine, hypovolaemia, fever, or arrhythmia may trigger the high pulse alarm. The low pulse alarm may be triggered by bradycardia secondary to vagal stimulation due to e.g. peritoneal retraction, the oculocardiac reflex or intubation (particularly in babies) or from deep anaesthesia (particularly halothane) or severe hypoxia. A highly trained athlete or a patient who is taking β-blockers may have a slow pulse rate.

WHAT FACTORS CAN INTERFERE WITH THE PULSE OXIMETER READING?

Several factors can interfere with the correct function of a pulse oximeter including:

- **Light** – bright light (such as the operating theatre light or sunlight) directly on the probe may affect the reading. Shield the probe from direct light.
- **Shivering** – movement may make it difficult for the probe to pick up a signal.
- **Pulse volume** – the oximeter only detects pulsatile flow. When the blood pressure is low due to hypovolaemic shock or the cardiac output is low or the patient has an arrhythmia, the pulse may be very weak and the oximeter may not be able to detect a signal
- **Vasoconstriction** reduces blood flow to the peripheries. The oximeter may fail to detect a signal if the patient is very cold and peripherally vasoconstricted.
- **Carbon monoxide poisoning** may give a falsely high saturation reading. Carbon monoxide binds very well to haemoglobin and displaces oxygen to form a bright red compound called carboxyhaemoglobin. This is only an issue in patients following smoke inhalation from a fire.

Learning point: Hypovolaemia is the most common cause of a weak pulse oximeter signal during anaesthesia. Hypothermia should also be considered.

WHAT IS NOT MEASURED BY A PULSE OXIMETER?

A pulse oximeter does not give direct information about respiratory rate, tidal volume, cardiac output or blood pressure. However, it does so indirectly and if these factors lead to desaturation, this will be detected by the pulse oximeter.

Learning point: Supplemental oxygen is often essential during anaesthesia. However, be aware that it can mask the effects of hypoventilation on oxygen saturation. Clinical vigilance will be necessary to ensure that ventilation is adequate especially if a capnograph is not available.

Pulse oximeters function normally in anaemic patients. In an extremely anaemic patient, the oxygen saturation will still be normal (95%-100%), but there may not be enough haemoglobin to carry sufficient oxygen to the tissues. In cases of severe anaemia, the patient should be given 100% oxygen to breathe during anaesthesia to try to improve tissue oxygen delivery by increasing the amount of dissolved oxygen in the blood.

UNDERSTANDING HOW OXYGEN DESATURATION OCCURS

PULSE OXIMETER QUIZ 3

The causes of hypoxia during anaesthesia can be attributed to problems with the **Airway**, **Breathing**, **Circulation**, **Drugs** or **Equipment**. By remembering to check the patient in this order, most of the causes of hypoxia can be identified and treated.

Using the headings below, consider what could go wrong during anaesthesia to cause hypoxia. Compare your answers to the table on the next page.

Airway

Breathing

Circulation

Drugs

Equipment

What do you think is the most common cause of hypoxia in theatre or recovery?

CAUSES OF HYPOXIA DURING ANAESTHESIA:

The causes of hypoxia during anaesthesia are summarised in the table below. **Airway obstruction is the most common cause of hypoxia.**

Causes of hypoxia in theatre – ‘ABCDE’

| Source of problem | Common problem |
|-----------------------|--|
| A. AIRWAY | <ul style="list-style-type: none">• An obstructed airway prevents oxygen from reaching the lungs• The tracheal tube can be misplaced e.g. in the oesophagus• Aspirated vomit can block the airway |
| B. BREATHING | <ul style="list-style-type: none">• Inadequate breathing prevents enough oxygen from reaching the alveoli.• Severe bronchospasm may not allow enough oxygen to reach the lungs nor carbon dioxide to be removed from the lungs.• A pneumothorax may cause the affected lung to collapse• High spinal anaesthesia may cause inadequate breathing |
| C. CIRCULATION | <ul style="list-style-type: none">• Circulatory failure prevents oxygen from being transported to the tissues• Common causes include hypovolemia, abnormal heart rhythm or cardiac failure |
| D. DRUGS | <ul style="list-style-type: none">• Deep anaesthesia may depress breathing and circulation• Many anaesthetic drugs cause a drop in blood pressure• Muscle relaxants paralyse the muscles of respiration• Anaphylaxis can cause bronchospasm and low cardiac output |
| E. EQUIPMENT | <ul style="list-style-type: none">• Problems with the anaesthetic equipment include disconnection or obstruction of the breathing circuit• Problems with oxygen supply include an empty cylinder or an inadequately functioning oxygen concentrator• Problems with the monitoring equipment include battery failure in the oximeter or a faulty probe |

Learning point: When hypoxia occurs, it is essential to decide whether the problem is with the patient or the equipment. After a quick check of the common patient problems, make sure the equipment is working properly. Always have a self-inflating bag available in case of problems with the breathing circuit.

WHAT SHOULD BE DONE WHEN THE SATURATION FALLS?

During anaesthesia, low oxygen saturations must be treated immediately and appropriately. The patient may become hypoxic at any time during induction, maintenance or emergence from anaesthesia. The appropriate response is to administer 100% oxygen, make sure that ventilation is adequate by using hand ventilation and then correct the factor that is causing the patient to become hypoxic. For example, if the patient has an obstructed airway and is unable to breathe oxygen into the lungs, the problem will only be cured when the airway is cleared.

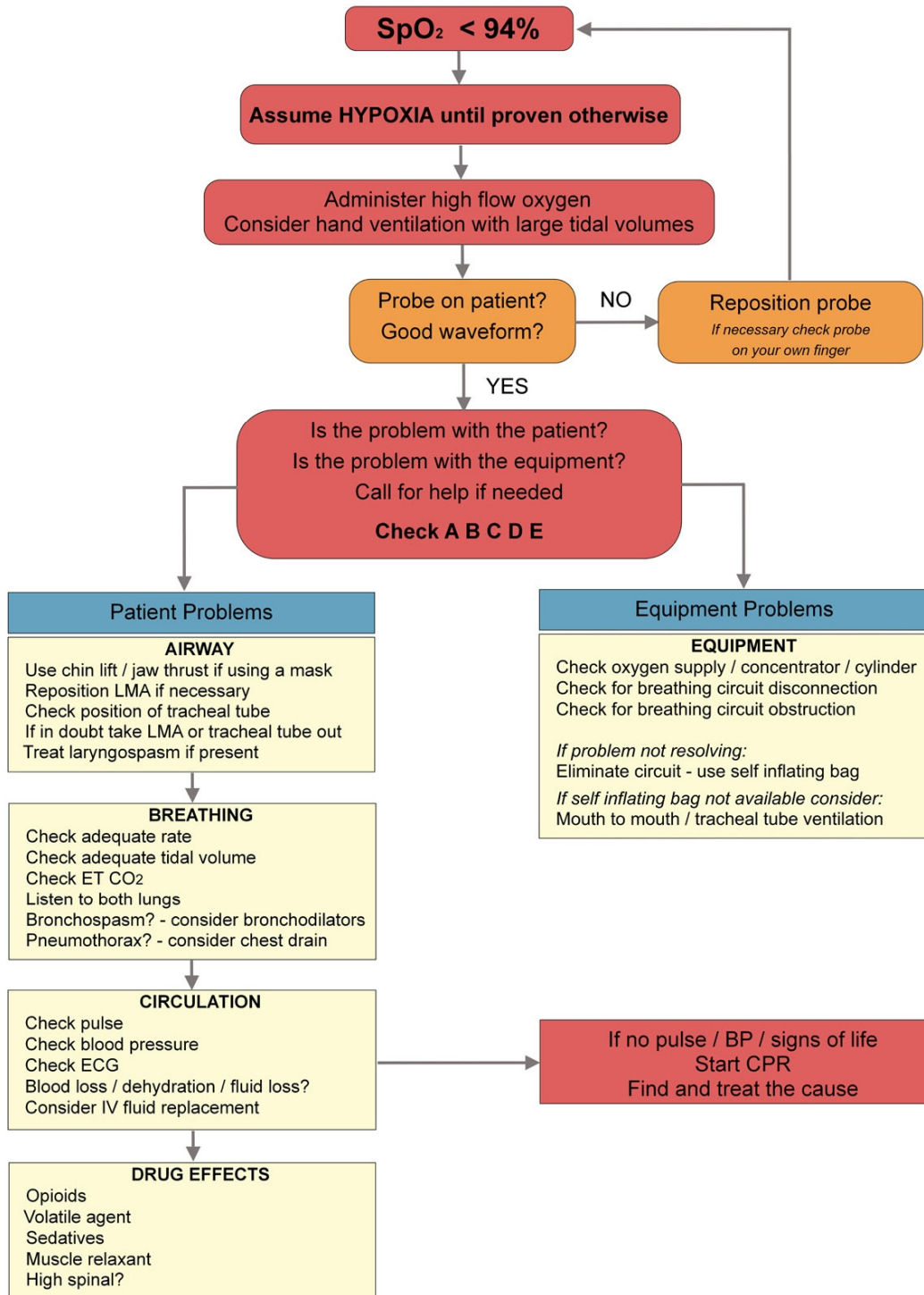
Whenever the patient has low oxygen saturations, administer high flow oxygen and consider 'ABCDE':

- **A - airway** clear?
- **B - breathing** adequately?
- **C - circulation** working normally?
- **D - drugs** causing a problem?
- **E - equipment** working properly?

You must respond to hypoxia immediately by giving more oxygen, ensuring adequate ventilation by hand, calling for help, and proceeding through the 'ABCDE' sequence. Treat each element of the sequence as you check it. After you have been through all the checks for the first time, go back and recheck them until you are satisfied that the patient's condition has improved. WHO has put this into a chart (below) to help you remember what to look for in a logical sequence. In an emergency, there may not be time to read through the protocol. You should ask a colleague to read it aloud for you to make sure that you have not forgotten anything.

Learning point: If SpO₂ is <94%, give 100% oxygen, hand ventilate, consider ABCDE

MANAGEMENT OF SpO₂ < 94%



ACTIONS TO TAKE IF THE OXYGEN SATURATION IS 94% OR BELOW

If the oxygen saturation is 94% or below, you should administer 100% oxygen, ventilate by hand, consider whether the problem is with the patient or the equipment, then move through the plan 'ABCDE', assessing each factor and correcting it immediately as you go.

Oxygen

Administer high flow oxygen if SpO₂ is <94%

A – Is the airway clear?

- Is the patient breathing quietly without signs of obstruction?
- Are there signs of laryngospasm? (mild laryngospasm – high pitched inspiratory noise; severe laryngospasm – silent, no gas passes between the vocal cords)
- Is there any vomit or blood in the airway?
- Is the tracheal tube in the right place?

Action

- Ensure that there is no obstruction.
 - If breathing via a facemask - chin lift, jaw thrust
 - Consider an oropharyngeal or nasopharyngeal airway
 - Check for laryngospasm and treat if necessary
 - Check the tracheal tube/LMA - if any doubt about the position, remove and use a facemask.
- Suction the airway to clear secretions.
- Consider waking the patient up if you have difficulty maintaining the airway immediately after induction of anaesthesia.
- Consider intubation.
- If you 'can't intubate, can't ventilate', an emergency surgical airway is required.

Airway obstruction is the most common cause of hypoxia in theatre. Airway obstruction is a clinical diagnosis and must be acted upon swiftly. Unrecognised oesophageal intubation is a major cause of anaesthesia morbidity and mortality. An intubated patient who has been previously well saturated may become hypoxic if the tracheal tube becomes displaced, kinked or obstructed by secretions. Check the tracheal tube and - **'If in doubt, take it out'**

B - Is the patient breathing adequately?

Look, listen and feel:

- Are the chest movement and tidal volume adequate?
- Listen to both lungs – is there normal bilateral air entry? Are the breath sounds normal? Any wheeze or added sounds?
- Is the chest movement symmetrical?
- Is anaesthesia causing respiratory depression?
- Is a high spinal causing respiratory distress?

Bronchospasm, lung consolidation/collapse, lung trauma, pulmonary oedema or pneumothorax may prevent oxygen from getting into the alveoli to combine with haemoglobin. Drugs such as opioids, poorly reversed neuromuscular blocking agents or deep volatile anaesthesia may depress breathing. A high spinal anaesthetic may paralyse the muscles of respiration. In an infant, stomach distension from facemask ventilation may splint the diaphragm and interfere with breathing. The treatment should address the specific problem.

Action

- Assist ventilation with adequate tidal volumes to expand both lungs until the problem is diagnosed and treated appropriately.
- If there is sufficient time, consider a chest X-ray to aid diagnosis.

The patient should be ventilated via a facemask, LMA or tracheal tube if respiration is inadequate. This will rapidly reverse hypoventilation due to drugs or a high spinal and cause a collapsed lung to re-expand. The lower airway should be suctioned with suction catheters to remove any secretions. A nasogastric tube should be passed to relieve stomach distension.

A pneumothorax may occur following trauma, central line insertion or a supraclavicular brachial plexus block. It should be suspected if there is reduced air entry on the affected side. In thin patients a hollow note on percussion may also be detected. A chest X-ray is diagnostic. A chest drain should be inserted to prevent the pneumothorax from worsening. When there is associated hypotension (tension pneumothorax), the pneumothorax should be treated by emergency needle decompression through the 2nd intercostal space in the mid-clavicular line without waiting for an X-ray. A definitive chest drain should be inserted later. Always maintain a high index of suspicion in trauma cases.

C - Is the circulation normal?

- Feel for a pulse and look for signs of life, including active bleeding from the surgical wound
- Check the blood pressure
- Check the peripheral perfusion and capillary refill time.
- Observe for signs of excessive blood loss in the suction bottles or wound swabs
- Is anaesthesia too deep? Is there a high spinal block?
- Is venous return impaired by compression of the vena cava (gravid uterus, surgical compression)
- Is the patient in septic or cardiogenic shock?

An inadequate circulation may be revealed by the pulse oximeter as a loss or reduction of pulsatile waveform or difficulty obtaining a pulse signal.

Action

- If the blood pressure is low, correct it
- Check for hypovolaemia
- Give IV fluids as appropriate (normal saline or blood as indicated)
- Consider head down or leg up position, or in the pregnant mother, left lateral positioning.
- Consider a vasoconstrictor such as ephedrine or phenylephrine
- If the patient has suffered a cardiac arrest, commence cardiopulmonary resuscitation (CPR) and consider reversible causes (4 H's, 4T's: **Hypotension, Hypovolaemia, Hypoxia, Hypothermia; Tension pneumothorax, Tamponade (cardiac), Toxic effects (deep anaesthesia, sepsis, drugs), Thromboemboli (pulmonary embolism).**

D – Drug effects

Check that all anaesthesia drugs are being given correctly.

- Excessive halothane (or other volatile agent) causes cardiac depression.
- Muscle relaxants will depress the ability to breathe if not reversed adequately at the end of surgery.
- Opioids and other sedatives may depress breathing.
- Anaphylaxis causes cardiovascular collapse, often with bronchospasm and skin flushing (rash). This may occur if the patient is given a drug, blood or artificial colloid solution that he/she is allergic to. Some patients are allergic to latex rubber.

Action

- Look for an adverse drug effect and treat as appropriate.
- In anaphylaxis, stop administering the causative agent, ventilate with 100% oxygen, give intravenous saline starting with a bolus of 10ml/kg, administer adrenaline and consider giving steroids, bronchodilators and an antihistamine.

E - Is the equipment working properly?

- Is there a problem with the oxygen delivery system to the patient?
- Does the oximeter show an adequate pulse signal?

Action

- Check for obstruction or disconnection of the breathing circuit or tracheal tube.
- Check that the oxygen cylinder is not empty
- Check that the oxygen concentrator is working properly
- Check that the central hospital oxygen supply is working properly
- Change the probe to another site; check that it is working properly by trying it on your own finger.

If it is felt that the anaesthesia equipment is faulty, **use a self-inflating bag to ventilate the patient with air** while new equipment or oxygen supplies are obtained. If equipment is missing, mouth to tracheal tube, or mouth-to-mouth ventilation may be lifesaving.

Quiz 4. Pulse Oximeter - demonstration

Demonstrate to the instructor or to a colleague:

1. How to charge the oximeter battery and store the accessories ready for clinical use.
2. How to select the most appropriate sensor for the patient.
3. How to apply the sensor to the patient correctly.
4. The battery condition indicator – what does the reading show?
5. How to switch on the monitor and describe the self-check routine.
6. The features of the main display.
7. The features of the waveform or pulse indicator.
8. How to adjust the alarm limits.
9. How to adjust the pulse sound volume.
10. How to turn the backlight on or off.

Answer the following two questions.

11. What conditions could cause inaccurate readings?
12. How should the sensor site be selected?

Quiz 5. Knowledge about pulse oximetry

Answer these questions about pulse oximetry – the answers are at the bottom of the page. More than one answer may be correct.

1. The pulse oximeter measures:
 - a. Haemoglobin level in blood
 - b. The amount of oxygen contained in the blood
 - c. Percentage of haemoglobin saturated with oxygen
 - d. Pulse rate
 - e. Cardiac output

2. Which of the following (if any) statements is true about oximeter probes?
 - a. Ear probes tend to read higher than finger probes
 - b. Probes are expensive
 - c. The probe can be cleaned gently with soapy water
 - d. If a signal is not present, the probe is always faulty
 - e. Nail varnish does not affect probe function

3. Which of the following can cause false readings on a pulse oximeter?
 - a. Dark skinned patients
 - b. Fast pulse rates with normal blood pressures
 - c. Overhead lights shining on probes
 - d. Carbon monoxide poisoning
 - e. Oxygen treatment

4. Oxygen saturation:
 - a. Should always be 100% during anaesthesia
 - b. Is normally above 95% in a healthy 2-year-old
 - c. Is normally less than 93% in a 70-year-old
 - d. Only becomes seriously low when under 75%
 - e. Is not worth measuring during spinal anaesthesia for Caesarean section

5. The following may reduce the chance of a successful oximeter reading:
 - a. Fever
 - b. Hypertension
 - c. Sickle cell disease
 - d. Arrhythmia
 - e. Hypovolaemia

The correct answers are

1. c, d
2. b, c
3. c, d
4. b
5. d, e

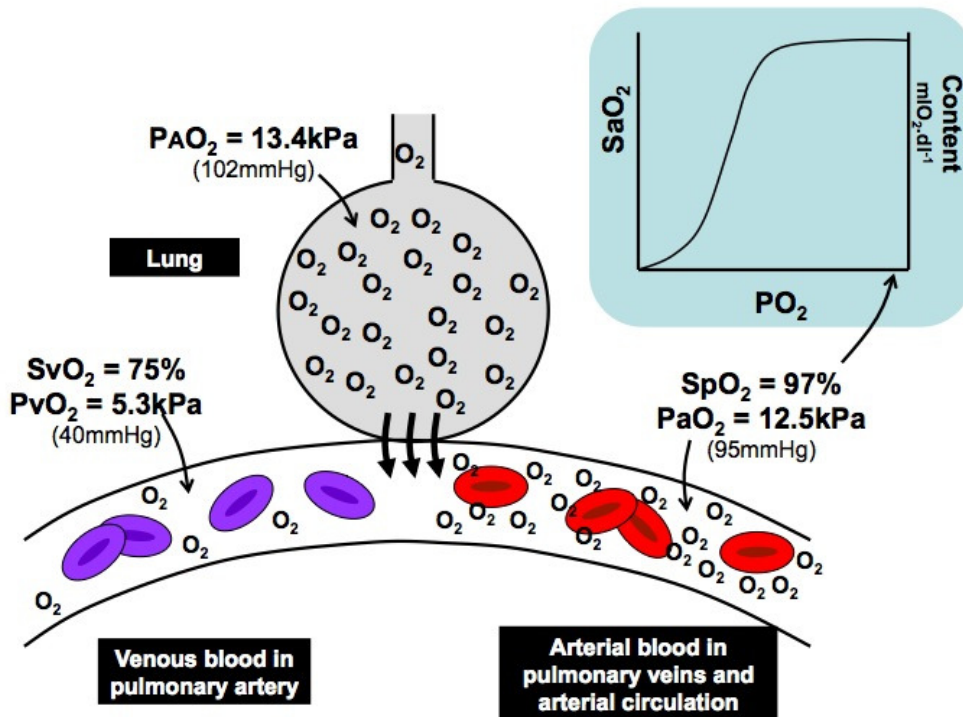
APPENDIX: FURTHER READING AND THE HAEMOGLOBIN OXYGEN DISSOCIATION CURVE

This section contains extra information about the way haemoglobin functions and how SpO₂ relates to arterial blood gases. There are also a number of references for further reading which may be accessed via the Internet.

Arterial blood gases and SpO₂

As previously explained, the pulse oximeter measures the oxygen saturation of haemoglobin in arterial blood. A blood gas analyser may be used to measure the oxygen content in a blood sample ('arterial blood gases'). The blood gas analyser describes the gas content as a partial pressure. It measures the partial pressure of oxygen (PaO₂) and carbon dioxide (PaCO₂), the pH of the blood and the bicarbonate concentration.

What is partial pressure? – The atmosphere is made up of a mixture of gases at a pressure of one atmosphere, 101kPa or 760mmHg. Oxygen is 21% of the atmosphere and the partial pressure of oxygen in air is 21kPa or 150mmHg. When blood is exposed to gases, the gas crosses into the blood down the pressure gradient. The partial pressure of oxygen and carbon dioxide in blood can be measured by analysing a sample of blood in a 'blood-gas machine' to assess the efficiency of oxygenation and ventilation. Oxygen saturation measured with a pulse oximeter gives a more useful minute-to-minute measurement of oxygenation, but gives no information about CO₂ or pH.



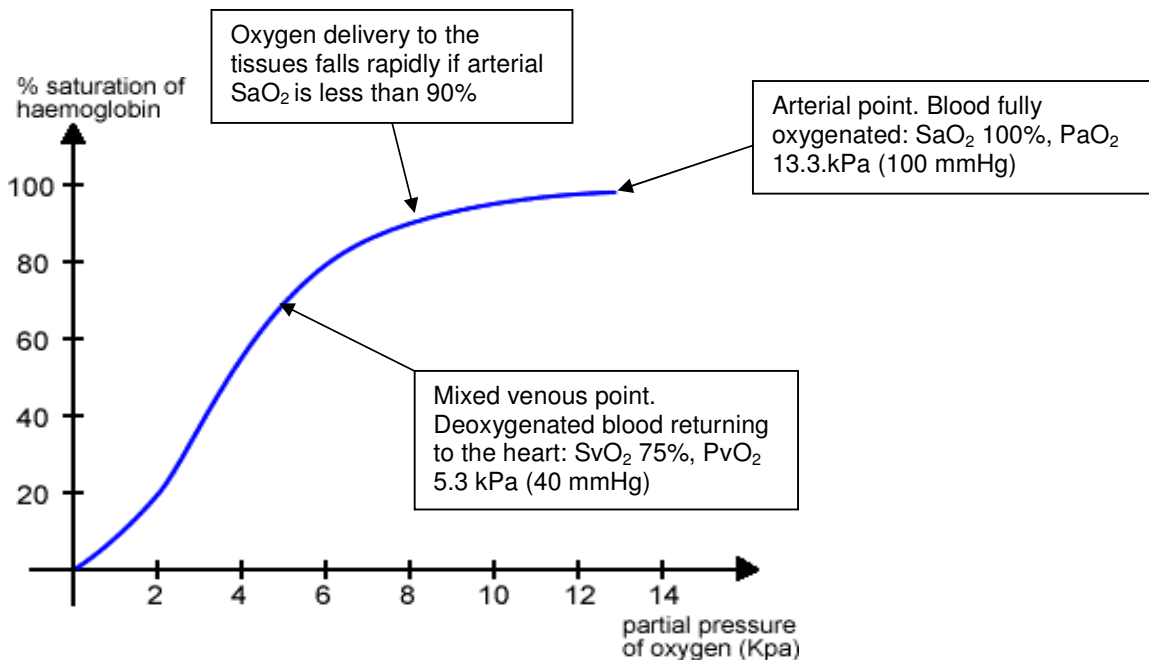
THE HAEMOGLOBIN OXYGEN DISSOCIATION CURVE

The relationship between the partial pressure of oxygen and the oxygen saturation is shown by the oxygen dissociation curve. As the partial pressure of oxygen in blood increases, so does the oxygen saturation. The sigmoid shape of the oxygen dissociation curve reflects the cooperative interaction between haemoglobin and oxygen molecules.

Some arterial gas analysers use the partial pressure of oxygen to estimate the haemoglobin saturation from a computer in the analyser, but this measurement is not as accurate as measured by a co-oximeter.

Gas exchange occurs in the lungs. The lungs are reloaded with fresh oxygen with each breath. Oxygen at a high partial pressure (PaO_2 13kPa or 100 mmHg) drives oxygen on to the haemoglobin until 95 – 100% is saturated. Haemoglobin releases oxygen as the blood passes through the tissues. The partial pressure of oxygen in blood returning from the tissues (mixed venous blood) is much lower than in arterial blood (PaO_2 5.3 kPa or 40mmHg).

The oxygen dissociation curve is initially steep, and then flattens out (sigmoid shape). The most important aspect of the oxygen dissociation curve is that, as the oximeter reading falls below 90%, the partial pressure of oxygen in the blood drops very rapidly and oxygen delivery to the tissues is reduced and may lead to cardiac arrest. You must intervene swiftly if the oxygen saturation drops below 90%.



FURTHER READING ABOUT PULSE OXIMETRY

1. Fearnley SJ. Pulse Oximetry. Update in Anaesthesia http://www.nda.ox.ac.uk/wfsa/html/u05/u05_003.htm
2. Hill E, Stoneham MD. Practical applications of pulse oximetry. http://www.nda.ox.ac.uk/wfsa/html/u11/u1104_01.htm
3. Principles of pulse oximetry. <http://www.oximeter.org/pulseox/principles.htm>

