Near Infrared Spectroscopy (NIRS): Guidelines for use in the Children's Intensive Care Unit (CICU)

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1. Background

NIRS allows for continuous non-invasive monitoring of regional venous oxygen saturation (rSO2) at depths of 1-4cm beneath the skin.

The algorithm for its use measures light absorption in non-pulsatile blood – because a majority of blood in the microcirculation is venous (~ 75%), the rSO_2 is used as a surrogate for venous oxygen saturation of the interrogated viscera. It provides information on the adequacy of the balance between regional tissue oxygen delivery and extraction. Its interpretation is analogous to the systemic venous saturations (SvO_2), indicating the balance between oxygen delivery and extraction, only more reflective of local tissue balance.

2. What is normal?

NIRS values (expressed as a percentage, from 0% to 100%) will vary with arterial saturation (SaO_2), so instead of a "normal" value, target a NIRS value that is acceptable for the arterial saturation (similar to the arterio-venous O_2 ($SaO_2 – SvO_2$) difference, a reading 25-30% less than the arterial saturation would be acceptable). In our daily clinical practice, the arterial saturation is estimated using the patient's saturation obtained by pulse oximetry (SpO_2), but can be accurately measured from arterial blood gas (ABG) co-oximetry if required.

While there is no consensus on what constitutes a significant reduction in rSO_2, it is suggested that a greater than 20% decrease in the baseline rSO_2 should prompt a search for reversible causes and consider making clinical changes aiming to restore the rSO_2 to baseline if possible.

The rSO_2 *trend* is more significant than the actual number.

Acceptable parameters:

ACYANOTIC CIRCULATION	CYANOTIC CIRCULATION *(more at risk of ischaemia and hypoxia because of reduced oxygen supply capabilities)*
• SpO_2 >95%, SvO_2 >65% • Cerebral rSO_2 >55% • Renal rSO_2 >65%	• SpO_2 ~ 75%, SvO_2 >50% • Cerebral rSO_2 >45% • Renal rSO_2 >55%

3. Probe Placement

NIRS provides information regarding regional tissue perfusion depending upon the site of the probe.

Cerebral NIRS

1 or 2 probes may be placed on the forehead (bi-frontal), allowing for continuous direct measurement of brain oxygenation through cerebral oximetry. In neonates and infants, cerebral NIRS can be a reliable surrogate measure for central/mixed venous saturation. The optimal probe position is on either side of the forehead. If placed in the midline, the reading will reflect the saturation of blood in the superior sagittal sinus.

Somatic NIRS

A probe may be placed over the lumbar area and/or abdominal wall to assess renal and splanchnic tissue oxygenation respectively. A suggested location for placing the probe is on the left flank just above the hip, overlying the left renal bed. (A probe over the right flank may pick up pooled blood in the liver).

We suggest routinely using a two-probe technique with one cerebral probe (rSO2-1) and one renal probe (rSO2-2) in our unit. Continually assessing the regional venous saturations of both the brain and below the diaphragm provides a more global indication of the adequacy of total cardiac output.

Considerations in older children (> 1 year):

Use of only the cerebral probe in this age range is recommended. The smaller infant probe will not provide adequate infra-diaphragmatic penetration to give accurate readings in larger children.

4. Setting up/ Practical aspects for consideration:

Ideally, NIRS should be connected pre-operatively when the patient is awake, well and stable. This allows for a baseline rSO2 value to be set. Upon return from OT following cardiac surgery, confirm if a baseline rSO2 was obtained for the patient. Note any subsequent rSO2 changes from baseline during the operative procedure.

If NIRS is only connected after cardiac surgery, a baseline rSO2 should still be recorded after proper probe placement, ensuring good contact with skin.

If a RIJV central line is in place, obtain a baseline central venous saturation (surrogate for mixed venous saturation) and compare this with the rSO2.

Variations/ Interference may be noted where there is increased superficial tissue, melanin, bilirubin and body wall oedema.

The skin where the NIRS probe is placed should be inspected regularly, similar to our practice with pulse oximetry site monitoring - every 4-6 hours by gently peeling back the

hypafix to show the full area under the probe. However, this will reduce the adhesive strength of the probe and may require reinforcement with a secondary adhesive. We recommend changing the NIRS probe every 48 hours if prolonged use is anticipated.

5. Clinical indications for use in the CICU

A. FOLLOWING CARDIAC SURGERY

- All neonates and infants < 1 year of age with cyanotic congenital heart disease OR at risk of developing LCOS following cardiac surgery.

  - Cyanotic congenital heart disease patients are typically dependent upon a balanced circulation
  - LCOS post-surgery or at risk of developing LCOS (e.g. post cardiopulmonary bypass, coarctation repair etc.)

Examples includes: (list is not exhaustive)

- Single ventricle physiology: pre and post stage 1 palliation (Norwood procedure)
- S/P BT shunt, PA band
- Poor ventricular function (EF < 30%)
- Post-op TGA, Ebstein anomaly, Truncus arteriosus
- Severe pulmonary hypertension
- Open chest
- On ECMO post cardiac surgery

B. OTHERS:

Consider use of NIRS in infants/ children with:
- Myocarditis/ Cardiomyopathy
- Any patient on ECLS: ECMO/ VAD
- Post-cardiac arrest

6. Troubleshooting

<u>Factors affecting cerebral oxygenation (NIRS)</u>

SUPPLY **(OXYGEN DELIVERY)**	DEMAND **(OXYGEN CONSUMPTION)**
- Cardiac Output: • HR • BP (Preload, contractility, afterload)	Temperature
- Arterial Oxygen Content: • Hb • SaO2 • PaO2	Cerebral activity: • Agitation • Seizures (clinical/ subclinical) etc.

- Cerebral Blood Flow: • Cardiac output (MAP) • PaCO2 • Cerebral vascular resistance • ICP • CVP • Shunts (e.g. PDA, BT shunt)	Infection / Sepsis

A ***low*** rSO_2 (< 40% or a change > 20% from baseline) value may indicate ***inadequate tissue perfusion*** OR ***excessive tissue oxygen consumption.***

Changes in rSO_2 should not be acted on in isolation – a global assessment for adequacy of cardiac output should also include: lactate, central/mixed venous saturation (SvO2) and clinical parameters.

The most common cause of a low rSO_2 with a normal SvO_2 is a low $PaCO_2$, which causes cerebrovascular vasoconstriction, hence reducing cerebral blood flow.

Steps:

1. Verify NIRS probe placement: ensure head is midline (esp. important in cerebral NIRS)
2. Check patient's *arterial* and mixed venous blood gases, inform a senior doctor.
3. Absolute cerebral rSO_2 value <40% may signify neurological ischaemia / hypoxia and may be associated with a poor neurological outcome. Seek senior medical advice immediately.

↓**Cerebral rSO_2 and Somatic rSO_2** (Decrease in global oxygen delivery or increased global oxygen consumption)

↓ Oxygen delivery suspected	↑ Oxygen consumption suspected
Augmentation (inotropes) and/or manipulation (vasoactive agents) of cardiac output	Optimize analgesia, sedation,
Consider red cell transfusion if bleeding/ anaemic	Fever? → Cooling to normothermia
Consider if arterial blood is optimally saturated (care in patients with parallel circulations as the ventilation changes may adversely upset the 'balance' - recruitment manoeuvres, ↑PEEP, ↑PIP, ↑FiO_2)	Consider Paralysis
	Look for & treat infection
	Look for & treat seizures

↓ **Cerebral rSO_2** (risk of neurological injury)

- Exclude thromboembolic event / intra-cranial haemorrhage. Consider need for neurological imaging if there is a clinical suspicion.
- Consider reasons for inadequate cerebral blood flow:
  - Ensure good cardiac output
  - If ↓ $PaCO_2$ noted, minimize ventilation (if on ECMO, consider reducing sweep gas flow)
- Address increased oxygen consumption if necessary: optimize sedation, treat seizures, hyperthermia etc.

↓ **Somatic rSO_2** (risk of renal or gut ischaemia / infarction)

- ↓Renal rSO_2 may reflect the presence of a PDA or a run-off lesion – lower infra-diaphragmatic arterial saturations contributing to lower renal tissue saturations.
- Excessive systemic vasoconstriction? (high dose vasopressin/noradrenaline)

Additional considerations for the patient on ECMO:

- Check arterial and venous cannula placement
- VA ECMO: ensure optimal circulating blood flow, diagnostic oxygenator membrane checks
- VV ECMO: ensure optimal circulating blood flow, diagnostic oxygenator membrane checks, exclude cardiogenic shock and need for inotropic support, exclude evidence of recirculation

It is unclear if anything should be done about a high rSO_2 value - if there is suspicion of raised ICP and cerebral rSO_2 is high then it may be reasonable to decrease cerebral blood flow by decreasing the $PaCO_2$, but do not make the patient hypocapnic. Always consult CICU consultant if making changes based on a high rSO_2 value.

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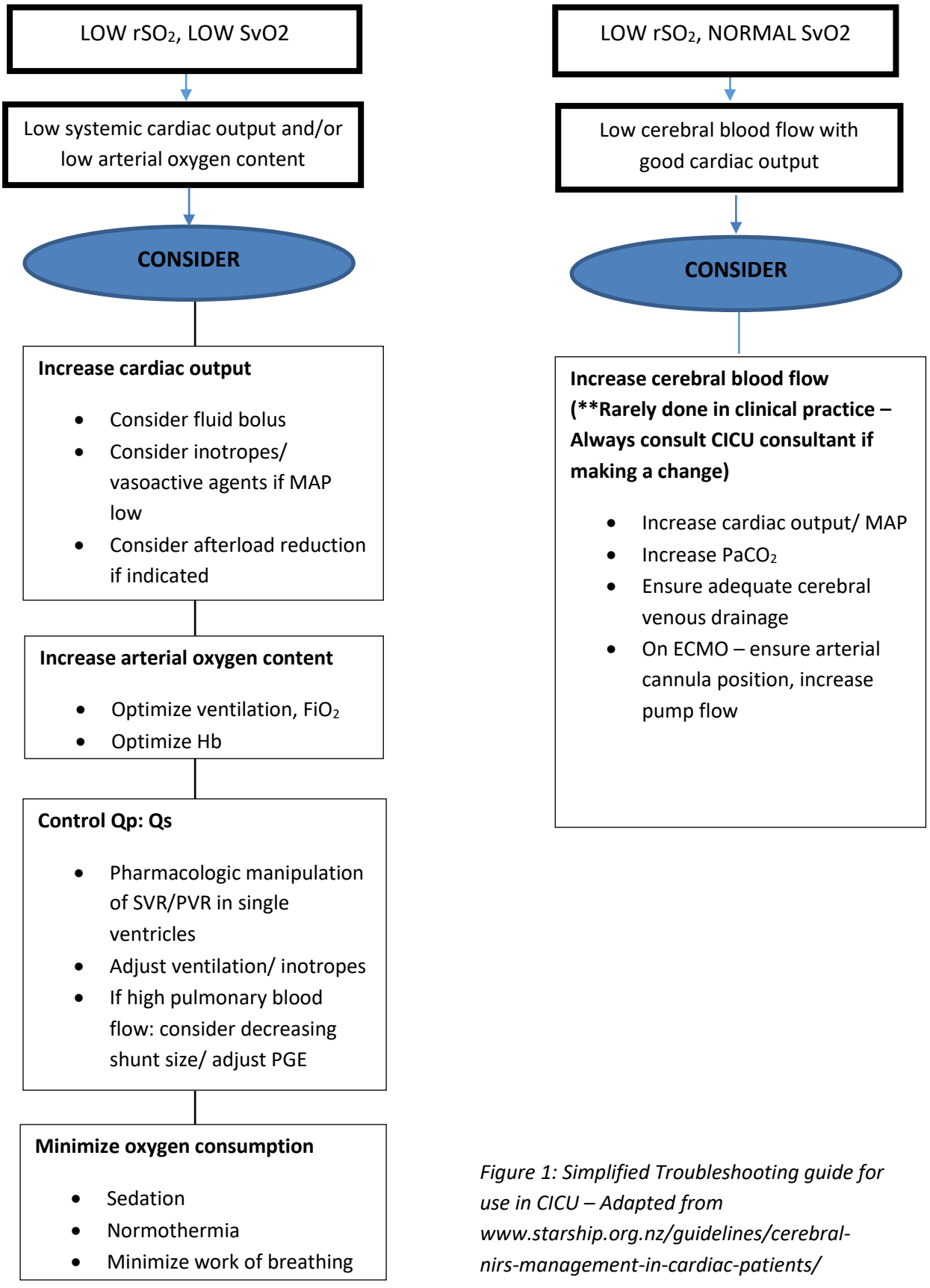

Figure 1: Simplified Troubleshooting guide for use in CICU – Adapted from www.starship.org.nz/guidelines/cerebral-nirs-management-in-cardiac-patients/