



NEST-ED

Technical Modules

February 2021

Newborn Essential Solutions and Technologies-Education (NEST-ED) Technical Modules provide educational support for each of the technologies included in the NEST360° bundle for newborn care. These materials are intended to strengthen locally developed neonatal and technical trainings in pre-and in-service settings and are not intended to be comprehensive technical guidelines or device-specific manuals.

**FACILITATING THE CLINICAL USE AND TECHNICAL
REPAIR OF TECHNOLOGIES FOR NEWBORN CARE
IN LOW-RESOURCE SETTINGS**

DISCLAIMER

Newborn Essential Solutions and Technologies-Education
Technical Modules: Pulse Oximeter

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Suggested citation. Liaghati-Mobarhan, S., Molyneux E., Werdenberg J. & Langton J., NEST360. *Newborn Essential Solutions and Technologies-Education – Technical Modules: Respiratory Support – Pulse Oximeter*. (February 2021). License: CC BY-SA 4.0.

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The authors have made every effort to check the accuracy of all information and instructions for use of any devices or equipment. As knowledge base continues to expand, readers are advised to check current product information provided by the manufacturer of each device, instrument, or piece of equipment to verify recommendations for use and/or operating instructions.

In addition, all forms, instructions, checklists, guidelines, and examples are intended as resources to be used and adapted to meet national and local health care settings' needs and requirements.

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PREFACE

This series has been designed with the intent of supporting the clinical use and technical repair of technologies in newborn care units.

Newborn Essential Solutions and Technologies-Education (**NEST-ED**) Technical Modules provide educational support for each of the technologies included in the NEST360° bundle for newborn care. These materials are intended to strengthen locally developed neonatal and technical trainings in pre- and in-service settings. Of note, these materials are not intended to be comprehensive technical guidelines or to replace the use of device-specific user and service manuals or textbooks. They are to be used to facilitate the implementation of comprehensive newborn care, including bubble CPAP, in a resource limited setting.

The NEST-ED Technical Modules were developed through a combination of international standard review, international expert feedback, and multinational NEST360° expert consensus opinion. NEST-ED Modules form the backbone of all lectures, power points, job aids, and other supportive education materials supplied by NEST360°.

**THIS IS ONE MODULE IN A SERIES OF NEST-ED
CLINICAL & TECHNICAL MODULES AVAILABLE.**

To view the full series, visit the [NEST360° Resources](#) website.

ABBREVIATIONS

bCPAP	Bubble continuous positive airway pressure
BMET	Biomedical Equipment Technician
dL	Decilitre
ESD	Electrostatic Discharge
FiO₂	Increased Fractional Concentration of Oxygen
Fr	French size
HAI	Hospital acquired infections
HCWs	Healthcare workers
KMC	Kangaroo mother care
LBW	Low birth weight
LCD	Liquid Crystal Display
LED	Light-Emitting Diode
mm Hg	Millimeters of mercury
NEST-ED	Newborn Essential Solutions & Technologies-Education
NEST360°	Newborn Essential Solutions & Technologies
nm	Nanometer
O₂	Oxygen
OGT	Orogastric tube
PCB	Printed Circuit Board
ppm	Parts per million
ROP	Retinopathy of Prematurity
PSA	Pressure Swing Adsorption
PSU	Power Supply Unit
ROP	Retinopathy of Prematurity
SpO₂	Peripheral blood oxygen saturation
UPS	Uninterruptible power supply
WASH	Water, sanitation and hygiene

NOMENCLATURE

Allen keys	Hex keys
bCPAP prongs	bCPAP patient interface
Christmas tree adapter	Barbed oxygen fitting, nipple and nut adapter
Control PCB	Main PCB
Cot	Bassinet, infant crib
Flat head screwdriver	Slot head screwdriver
Flow splitter	Oxygen splitter, flow meter stand
Glucometer	Glucose meter
Hospital Acquired Infection	Iatrogenic infection, nosocomial infection
Multimeter	Digital multimeter, Avometer
Nasal prongs	Oxygen catheter, oxygen cannula, oxygen prongs
Positive Pressure	Positive end expiratory pressure, positive airway pressure
Radiant warmer	Resuscitaire, resuscitation table
Star screwdriver	Torx screwdriver
Suction pump	Suction machine

Introduction

The NEST-ED Technical Modules have been prepared to help technical staff and students understand the basics of when and how to use equipment essential to newborn care. More importantly, the Technical Modules support staff in troubleshooting common issues, as well as prepare staff to repair equipment when it breaks down or malfunctions. Modules may be used by teaching institutions, to supplement current newborn care curricula, or by hospitals, clinical departments and individuals to update their knowledge and to better facilitate the effective and safe use of newborn care equipment. Modules should be used alongside device user and service manuals to provide additional context as needed.

Whilst reading this series, navigate to the **Table of Contents** by clicking the NEST360° logo that appears at the bottom right corner of each page: **NEST360°**

Every module has a similar structure with sections and subsections. The sections have similar headings and subheadings to make it easy for the user to navigate them. However, words may have different meanings for the various cadres of staff reading them and so to reduce misinterpretation, the heading titles are explained below.

The NEST-ED Technical Modules are intended as a flexible resource that hospitals and partners can adapt to their specific needs. The Technical Modules consist of generic content that can be applied to any model within a device category, coupled with model specific device images that can be exchanged for alternative images depending on the devices available at your facility. Individuals who are interested in gaining access to the editable NEST-ED Technical Modules should contact the **NEST Training Materials Coordinator** (Anniina Lockwood, al90@rice.edu) or the **NEST Biomedical Tech Training Director** (Sara Liaghati-Mobarhan, slmobarhan@rice.edu).

CLINICAL PROBLEM

This section provides useful information on the clinical application of a device that would bear relevance to the biomedical team, not only to aid in their troubleshooting, but also for user training.

ASSESSMENT

This section explains how the device works, and what kinds of patients it is useful for. This section also includes comprehensive diagrams of internal and external views of the devices, including consumables that may be used with the device. This section also contains detailed descriptions of key device components (including alarms) and includes a diagram of typical device flow (including components and how they interact with each other, electrical current and fluid movement through the device if relevant).

MANAGEMENT

This section focuses on **clinical** management and provides step by step directions on how to set the device up for a patient, followed by instructions on starting the patient on the device and monitoring a patient whilst on the device. This section also describes how to remove the equipment from the patient when it is no longer needed. Although a biomedical engineer or a technician will not be responsible for providing care, understanding these steps will be useful in training and when assessing the device.

INFECTION PREVENTION

This section lays out the basic infection prevention measures that should always be taken when handling equipment, followed by directions for disinfecting the equipment both during and after use. This section also describes the crucial Infection Prevention and Control steps that are particularly relevant to biomedical engineers and technicians.

COMPLICATIONS

This section explains some of the common but serious clinical complications that relate to and can arise from the use of the equipment (e.g., complications that will be seen or directly apply to the patient). Biomedical engineers' and technicians' understanding of potential complications for the patient is crucial to ensure patient safety. This section also describes common device complications (e.g., complications that will be seen or directly apply to the device).

CARE & MAINTENANCE

This section describes where to place equipment for use, how to safely handle devices and their consumables, whether calibration is recommended, and how to decommission the equipment. Biomedical engineers and technicians are responsible for second-line care and maintenance to ensure the equipment lasts to their potential lifetime; as such, this section also lists the necessary daily, weekly, monthly and annual preventive maintenance steps required to keep the device in good working condition. First-line care and maintenance is the responsibility of the user and is described in the **NEST-ED Clinical Modules**.

TROUBLESHOOTING & REPAIR

This section describes steps that should be taken when a device malfunctions and first-line troubleshooting efforts have failed to address the issue. This section describes tools and spare parts that might be required to prepare for repairs and to troubleshoot failures, and provides a list of components commonly provided with the device to ensure that all components return to the ward post-repair. Finally, this section also explains steps for testing, repairing, and replacing specific parts of the device.

REFERENCES & ALERTS

References & alert boxes are included within each module to provide clarity on areas where recommendations are governed by published standards, evidence, and/or expert opinion. This is included for the dual purpose of facilitating (1) feedback and continuous improvement of NEST-ED Technical Modules and (2) implementer review of content for incorporation in local trainings.

ALERT 0.0 Subject

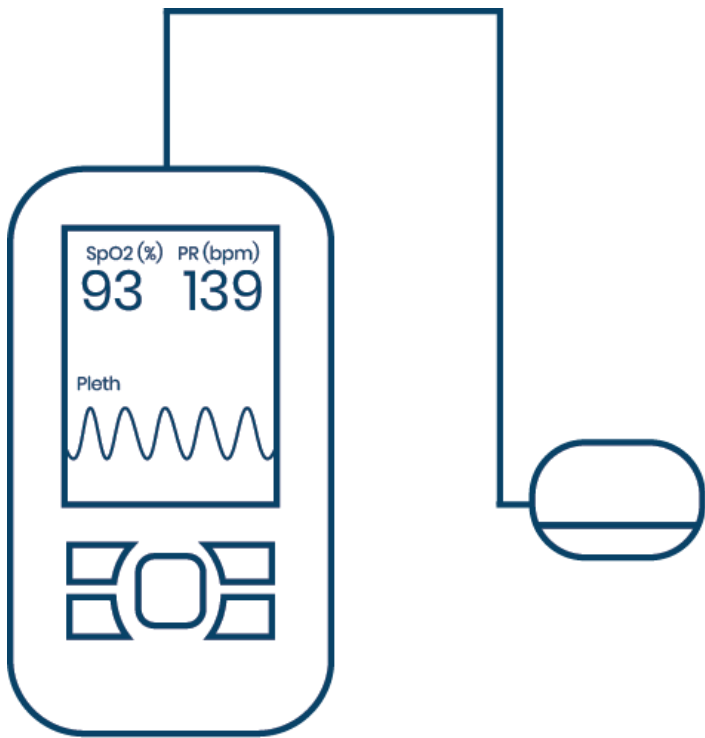
QUERY ALERT BOXES appear where there may be controversy or disagreement. In these cases, alert boxes provide background to the recommendations that are made in the body of the document. Relevant documents are cited and brief explanation of reasoning for current module content provided.

ALERT 0.0

RECOMMENDATION ALERT BOXES appear where there are recommendations based largely on expert opinion or consensus, or to emphasize an important element of care. Relevant documents are cited and brief explanation of reasoning for current module content provided.

Respiratory Support

Pulse Oximeter



1 Clinical Problem

Assessment of oxygen saturation with a pulse oximeter is necessary in clinical management of patients in all hospital settings. In newborn care units, pulse oximeters are used during routine assessment on admission and for continuous monitoring of patients.

Pulse oximeters should also be used during treatment for all sick or at-risk patients, or those on oxygen therapy **(1.1a, 1.1b)**, CPAP **(1.2)**, or any form of assisted ventilation. **(1.3)**



1.1a Oxygen concentrator.



1.1b Oxygen cylinder.



1.2 Bubble CPAP.



1.3 Ventilator.

2 Assessment

Peripheral pulse oximetry is a non-invasive method of measuring pulse rate and oxygen saturation (oxygen bound to haemoglobin in the capillaries) using infrared & red light.

Pulse oximeters may be used to help determine the severity of an infant's illness by evaluating if blood oxygen saturation (SpO_2) is low and if respiratory support is needed. Pulse oximeters also may be used to assess the success of treatment and determine a need for increasing or decreasing respiratory interventions to achieve target SpO_2 . Pulse oximeters may be:

- Fixed/tabletop **(2.1)** (for continuous reading of one patient)
- Handheld **(2.2)** (for continuous or spot reading of vital signs)

- Finger clip **(2.3)** (for spot reading of vital signs; **only appropriate for adult or older paediatric patients. NOT recommended for use in neonatal patients**)



2.1 Fixed pulse oximeter

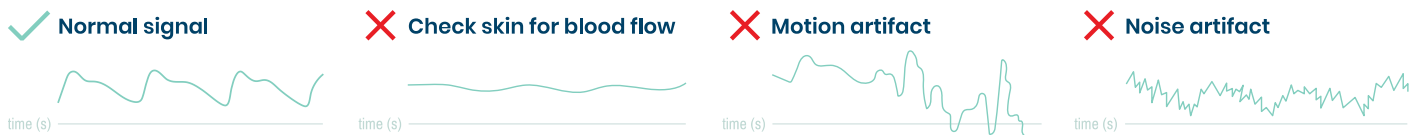


2.2 Handheld pulse oximeter



2.3 Finger clip oximeter; not for use in neonatal patients.

To facilitate more accurate readings, patient signal should be both strong and stable. Patient movement, blood flow and external sources of light may impact the stability of the patient's trace. Examples of a "normal signal" and potential "poor traces" are below. **(2.4)**



2.4 Trace examples. Blood saturation is recorded over time.

The same tabletop and handheld pulse oximeter can be used for adult, paediatric, and neonatal patients. The alarm settings on the pulse oximeter should be changed accordingly and appropriately sized probes used. Probe size will vary depending on patient age. **Finger clip pulse oximeters are not recommended for use in neonatal patients.**

Normal SpO₂ for neonatal patients should be:

- 90%–100% if not on oxygen**
- 90–95% on oxygen (Alert 2.1)**

If SpO₂ readings are less than 90% 15 minutes after birth, the patient should be considered for supplemental oxygen therapy (see oxygen concentrator module). **Assess that the reading accurately reflects the clinical situation of the patient by checking the correspondence between oxygen saturations, heart rate, and clinical condition.**

? Alert 2.1 Oxygen targets in newborns

Exact oxygen saturation targets for premature newborns remains an area of controversy. However, most authorities agree that saturations between 90–95% are reasonable to minimise complications associated with low and high oxygen levels, including death, neurodevelopmental impairment, and retinopathy of prematurity.^{1–4}

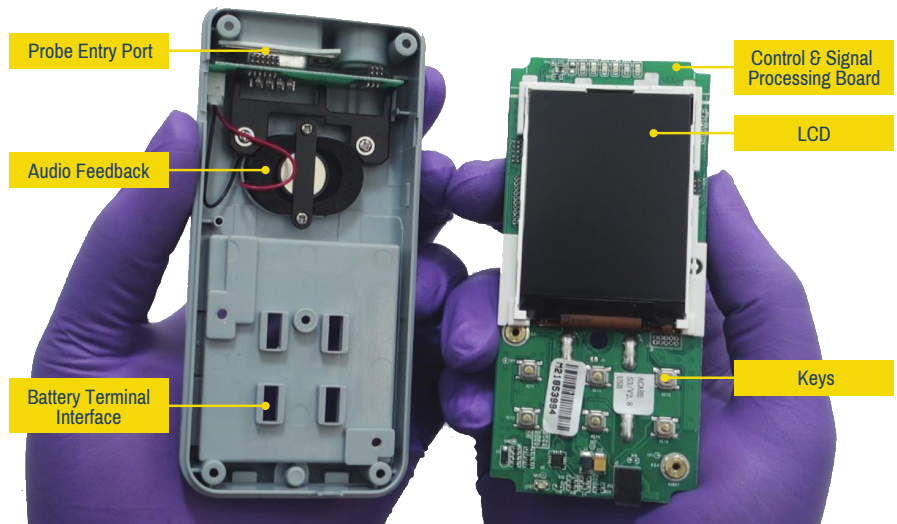
HOW IT WORKS

Oxygen is carried in the bloodstream by binding to haemoglobin in red blood cells. Each haemoglobin can carry four oxygen molecules and at that point becomes 100% saturated. The colour of blood depends on how much haemoglobin is saturated with oxygen. Haemoglobin that is carrying oxygen is called oxygenated haemoglobin (oxyhaemoglobin) and appears bright red, while deoxygenated haemoglobin (deoxyhaemoglobin) appears dark red.

Pulse oximeters differentiate between the light absorbing properties of oxygenated haemoglobin and deoxygenated haemoglobin at two different wavelengths in red spectrum and use this differential and changes in local blood volume (resulting from heartbeat pulses) to calculate SpO₂ of pulsating arterial blood.

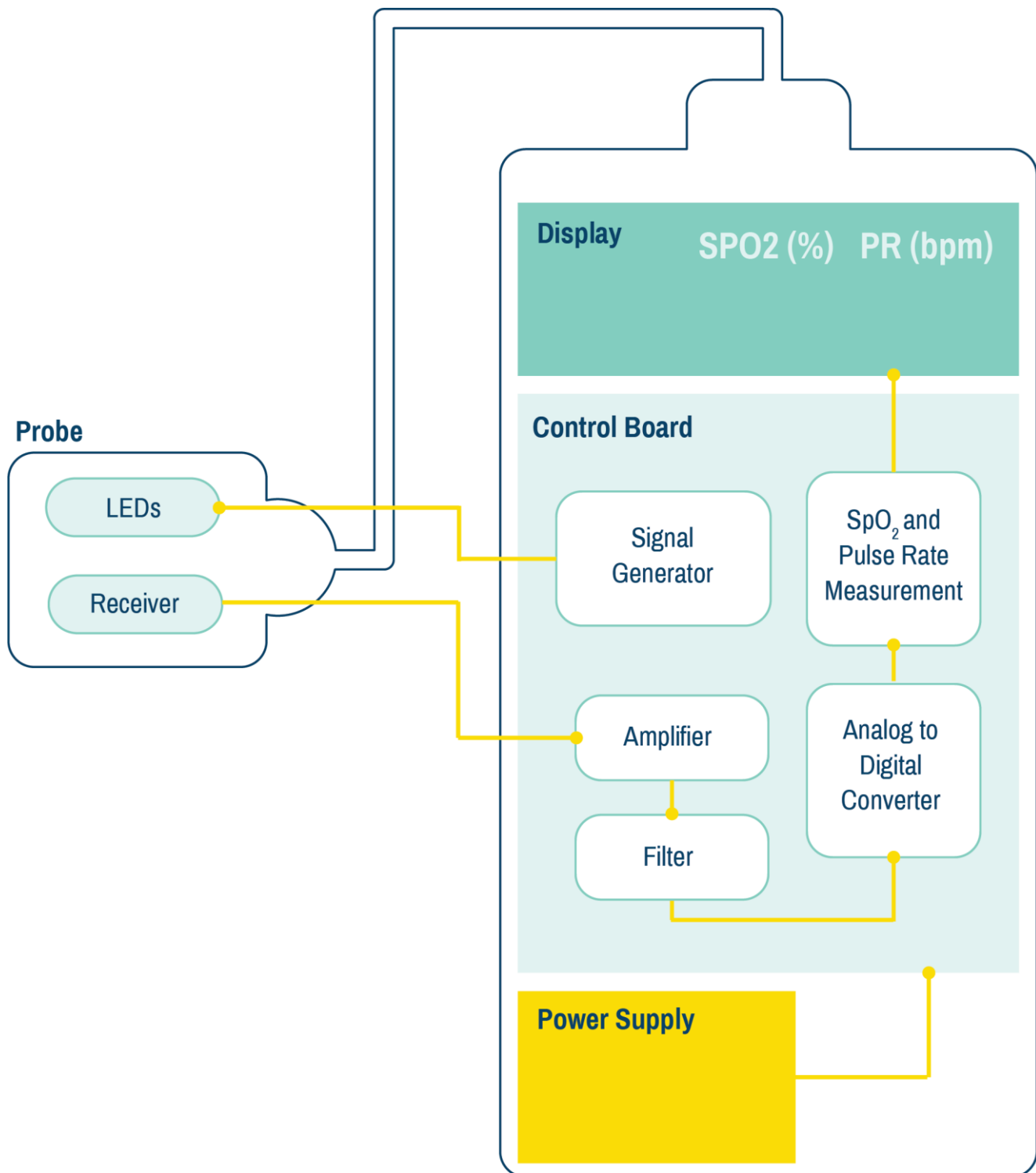


2.5 Main external components of a pulse oximeter.



2.6 Main internal components of a pulse oximeter.

TYPICAL DEVICE FLOW



Electrical Signal

MAIN COMPONENTS

The following device components should be similar regardless of model. However, specific locations, visual setup and component type may vary by brand and device model. Refer to model service and user manuals if different from the displayed model for more device-specific information.

LCD

A typical pulse oximeter displays the oxygen saturation, heart rate and the plethysmograph (or waveform of measured pulses). Some additional features may include perfusion index, battery power, alarm limits, and visible (and audible) warning lights and indicators.

Probe

The probe is made up of a sensor, cable and attachment head and is the first point of failure for most pulse oximeters.

The pulse oximeter probe sensor has two main components: a photodiode and a pair of LEDs that emit red and infrared light (typically in wavelengths of 660 nm and 940 nm, respectively). These components may be arranged transmissively (with the LEDs and photodetector arranged opposite to each other, with the body measurement site in between) or reflectively (with the LEDs and photodetector arranged next to each other, along the body; in this instance, the photodetector collects light signals bounced back from the body tissue). The most common of these probes is transmissive, making selecting the correct location critical to collect a measurement. When attached to the peripheral tissue (ear, finger or foot), oxyhaemoglobin partially absorbs the infrared light (at a 940 nm wavelength) and deoxyhaemoglobin (venous and capillary) absorbs red light (at a 660nm wavelength). The non-absorbed transmissive or reflective light signals are then detected by the photo detector.

Pulse oximeter probes may be proprietary to the device brand or generic. The entry port should exactly match the end of the probe. In most ports, there is only one way to correctly connect the probe. Generic probes may need an adapter to fit into the pulse oximeter device port. The adapter typically has a proprietary end and a generic entry port.

Control Circuit Board

Located internally, the control circuit board mainly consists of memory circuits, multiplexers, current to voltage converters, filters and a microprocessor.

The control PCB identifies and isolates the absorbance of the pulsatile fraction of arterial blood component light signals from the absorbance due to non-pulsatile light signals from capillary blood. These signals then undergo amplification, filtration and artefacts rejection. The microprocessor determines the percent of oxygen in the blood by comparing the concentration of oxyhaemoglobin to deoxyhaemoglobin at two different light wavelengths using the formula below.⁵

$$SpO_2 = \frac{O_2H_b}{O_2H_b + H_b} \times 100\%$$

O_2H_b = oxyhaemoglobin
 H_b = deoxyhaemoglobin

Formula 2.1 SpO₂ Calculation

3 Management

Management covers how to use the pulse oximeter, including set up for a patient, patient commencement, care whilst on the device and removal of the patient from the device. These instructions are helpful for a biomedical engineer or technician both in user training and in assessing the appropriate functionality of the device.

SETTING UP FOR A PATIENT

- 1 Follow hand washing procedures.
- 2 Collect:
 - Pulse oximeter
 - Pulse oximeter probe
 - 70% alcohol solution
 - Cotton swab
- 3 Connect the probe. **(3.1)**
 - Check the shapes of the pulse oximeter port and the external probe sensor. If these are not the same size, an adapter is needed. This should be provided with the pulse oximeter.
 - Connect the probe connector to the pulse oximeter probe port, paying attention to the orientation of the probe and probe port. Be careful not to bend the pins as the probe is inserted.
- 4 Turn on pulse oximeter by pressing and holding the power button. **(3.2)** The display should turn on.



3.1 Connect probe.



3.2 Turn on pulse oximeter.

- 5 Check for a red light on the probe. If the probe displays a red light, take steps to prepare patient for device. If the probe does not display a red light, follow the guidelines in **Pulse Oximeter: Troubleshooting & Repair | If the pulse oximeter is turning on, but no trace is showing**.
- 6 Clean the pulse oximeter probe thoroughly using alcohol and a cotton swab.

STARTING A PATIENT

Follow hand-washing procedures. Select best location on patient to collect reading (e.g., on the wrist/foot or fingers/toes) and clean location with alcohol and gauze.

- 1 Adhesive (disposable) wrap probe:
 - Remove the wrap probe from its packaging and peel from its plastic base.
 - Place the part of the tape with the sensor, sensor side down, on the wrist whilst palm-side up or on the sole of the foot. The wrist is only suitable for preterm babies.
 - Wrap the adhesive strip around the wrist or foot to secure in place.
- 2 Rubber (reusable) wrap probe: **(3.3)**
 - Place the part of the wrap probe with the sensor, sensor side down, on the wrist whilst palm-side up or on the sole of the foot. **(3.4)**
 - Wrap the rubber connecting strip around the wrist or foot **(3.5)**, thread through hole and tighten to secure in place. **(3.6)** Ensure the light and sensor are opposite each other.
- 3 Clip probe:
 - Squeeze tips of the clip probe to open. Place gently on patient's fingers or toes and release.

Wrap and clip probes should be firmly placed without need to be held. **The probe should not be so tight as to cause pressure on the skin or impair circulation.**



3.3 Rubber wrap probe.



3.4 Rubber wrap probe is placed sensor-side down on the sole of the foot.



3.5 Wrap rubber connecting strip around foot.



3.6 Thread through hold & tighten to secure.

CARING FOR A PATIENT

- 1 Allow the patient's trace to stabilise before reading SpO₂ and heart rate. **(3.7)** These should correspond to patient's clinical condition. If they do not correspond, reposition the probe to ensure good contact with the patient.
- 2 Record SpO₂ and heart rate in patient documentation. Pulse oximeters are inaccurate for readings under 70%; readings between 20% and 60% do not correlate to clinical deterioration or improvement. **(Alert 3.1)** A low reading should alert you to look for a problem with the probe fixation, baby or oximeter.
- 3 If continuously monitoring patient, periodically check the sensor site **(3.8)** during monitoring for evidence of skin damage. If the pulse oximeter probe is attached too tightly, inappropriately or too long at one site, pressure sores may develop. The warmth of the light may irritate the skin of a premature baby which is why the probe needs regular repositioning.



3.7 Allow the patient's trace to stabilise.



3.8 Check sensor site for signs of skin damage.

Alert 3.1 Accuracy Thresholds for Pulse Oximeters

*WHO-UNICEF Technical Specifications and Guidance for Oxygen Therapy Devices*⁶ lists accuracy of $\pm 2\%$ between 70–100% SpO₂ as a minimum requirement for all types of pulse oximeters. Additionally, during NEST360° technical testing and review, most (if not all) devices were only tested by the manufacturer to guarantee accuracy within a certain precision between 70–100%.

REMOVING A PATIENT

Removing the probe from the patient varies based on the type of probe in use:

- 1 **If using an adhesive wrap probe:** peel adhesive away from patient and pull probe away from patient. Disinfect probe site on patient and wrap probe with 70% alcohol if reusing.
- 2 **If using a rubber wrap probe:** unthread rubber connecting strip through the hole. Pull probe away from patient. Disinfect probe site on patient and the wrap probe with 70% alcohol.
- 3 **If using a clip probe:** press on the tips of the clip probe to open. Gently pull away from patient. Disinfect probe site on patient and clean probe with 70% alcohol.

4 Infection Prevention

Routine and adequate cleaning of medical devices is critical to prevent hospital-acquired infections in newborn care units.

CLINICAL INFECTION PREVENTION

- 1 Clean hands with soap and water or 70% alcohol before and after assessing a patient using a pulse oximeter or handling any probes that will be used on a patient.
- 2 Ensure that all patient-related consumables (including probes) are new or have been cleaned thoroughly before use. Any patient-related consumables must be cleaned before they are used to assess another patient using the pulse oximeter.
- 3 When using the pulse oximeter, the device should be placed in a secure location to prevent drops and breakages. **The device should never be placed inside a bed, cot or bassinet.**

DISINFECTION AFTER USE

- 1 Clean reusable probes with 70% alcohol. Adhesive probes are specified for single-use; if reusing, disinfect sensor with alcohol. **(Alert 4.1)**
- 2 If pulse oximeters or patient consumables (including probes) are not cleaned thoroughly before use, infection can be transmitted. Care should be taken particularly for consumables marked as single-use but are reused (such as adhesive wrap probes). Between patients, wipe down the pulse oximeter with alcohol. **(4.1)** Be careful not to submerge or drip alcohol onto the pulse oximeter or any of its cables.



4.1 Wipe down the pulse oximeter probe and pulse oximeter with alcohol-soaked gauze between patients.

! Alert 4.1

While many pulse-oximeter probes are designed to be single use devices, cost and logistical constraints make this unrealistic in many low resource settings. Recommendations for cleaning single use devices were taken from [Infection Prevention and Control: Reference Manual for Health Care Facilities with Limited Resources, Jhpiego.](#)⁷ Vigilance by healthcare workers to assess that pulse-oximeter readings correlate to patient's heart rate and clinical condition is especially critical when re-using probes meant for single-use. It is not known how rapidly pulse-oximeter probes degrade or become inaccurate with re-use.

BMET INFECTION PREVENTION

- 1 Any piece of equipment used in providing patient care must be handled carefully, as it may be contaminated and have the potential to spread infection.
- 2 Clean and disinfect pulse oximeter housing and components whilst wearing PPE as appropriate (e.g., rubber gloves, apron, face protection, etc.) **before any repairs or maintenance are made.**
- 3 Avoid any contact between used piece of equipment and skin, mucosa or clothing.
- 4 Post-maintenance decontamination of all tools and surfaces used should be done with 70% alcohol or according to manufacturer guidelines. Do not use equipment until it has fully dried following decontamination.

Alert 4.2 Disinfecting Equipment

Disinfection of equipment should always comply with manufacturer guidelines. WHO recommends 0.5% dilution of chlorine (0.5% or > 100ppm available sodium hypochlorite) as the standard disinfectant for materials and surfaces contaminated by blood or body fluids.⁸ For metal and rubber surfaces, which may be corroded by chlorine, 70% alcohol is also commonly utilised for low level disinfection.

Other appropriate low-level disinfectants include quaternary ammonium, improved hydrogen peroxide and Iodophor germicidal detergent.⁷ Phenolic germicidal detergent is also identified but should not be used in neonatal wards since affordable, effective alternatives are available; and, there are concerns it may cause hyperbilirubinemia and/or neurotoxicity in neonates.⁹

See dedicated NEST360° module on Infection Prevention and Control for further details on risks, benefits and utilisation of chemical disinfectants. For comprehensive guidance on infection prevention and control we recommend utilising Reference Manual for Health Care Facilities with Limited Resources Infection Prevention and Control (Caston-Gaa & Ruparelia, 2018).

5 Complications

Equipment in newborn care units are highly specialised. Without proper knowledge and skills, this equipment can be potentially dangerous for the infants, families and care providers.

CLINICAL COMPLICATIONS

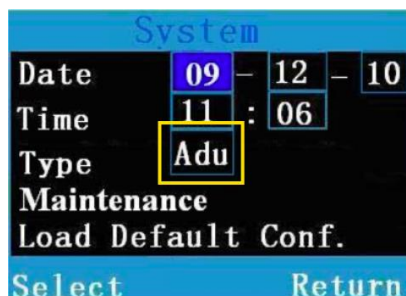
- **Misdiagnosis:** a poor trace **(5.1)** may contribute to misdiagnosis and can result from:
 - **Hypovolaemia/hypotension:** poor peripheral perfusion may cause a false reading
 - **Movement:** may create noise on the trace or delay the stabilisation of the trace
 - **Peripheral cyanosis/anaemia:** poor oxygen delivery to the tissues, compromises measured saturation. **Saturation readings below 70% are not reliable as clinical guides.**
 - **Hypothermia:** causes poor peripheral perfusion, which can provide an inaccurate representation of the oxygen saturation within the blood.
- **Pressure sores:** if the pulse oximeter probe is attached too tightly, inappropriately or too long at one site, pressure sores may develop. The warmth of the light may irritate the skin of a premature baby which is why the probe needs regular repositioning.

DEVICE COMPLICATIONS

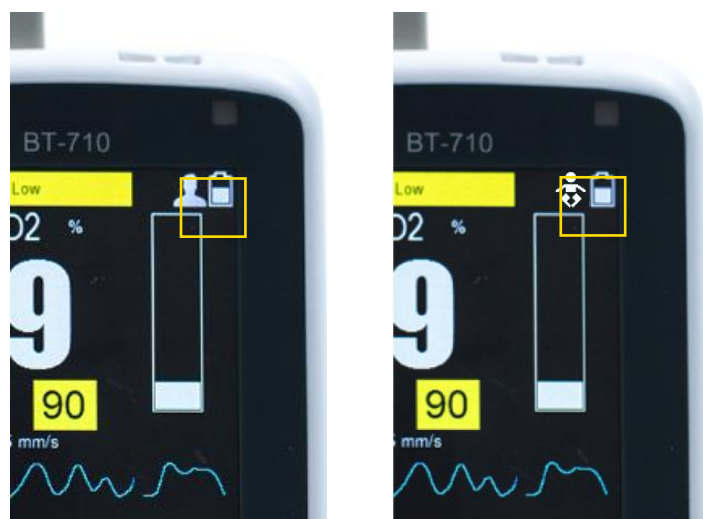
- **Poorly fitting probes can lead to inaccurate saturation measurements:** if the probe is too large for the patient, the probe will shift in place, creating issues both in terms of inconsistent measurement due to multiple contact points as well as the potential to have

no direct contact points with the skin. If the probe is too small for the patient, blood flow may be constricted. Also, the light and sensor must be positioned opposite each other.

- **Patient movement:** as the patient moves, the contact point between the probe and the patient moves along the patient's skin. This movement provides an inconsistent measurement because it samples from various contact points in the skin, rather than remaining in the same contact point of tissue. This may cause the reading to be noisy or take time to stabilise. Some oximeters designed for newborns have purpose-built motion-cancelling algorithms to minimise false readings and alarms.
- **Strong light:** if strong light (e.g., phototherapy, exam lights, or sunlight) is on a probe sensor, the light signal from the pulse oximeter probe may be drowned out by the stronger environmental light, leading to incorrect results. A cloth covering of the sensor site will protect it from bright light.
- **Oximeter alarm settings:** pulse oximeters may have adult, paediatric, and neonatal settings in the same device. **(5.2)** Pulse oximeters are usually set to a default adult setting. If the pulse oximeter is not set to neonatal parameters, alarms may sound inappropriately. If settings are visually incorrect, check the user manual for device-specific instructions on changing the settings.



5.1 Pulse oximeter set to adult.



(A)

(B)

5.2 Icons designating adult (A) and neonatal (B) settings.

6 Care & Maintenance

Biomedical engineers and technicians are responsible for second-line care and maintenance to ensure equipment lasts to their potential lifetime.

POWER SOURCE

A pulse oximeter is powered by replaceable or rechargeable **(6.1)** batteries. If using a rechargeable device, users should regularly charge the pulse oximeter when not in use to ensure power in the event of an outage.



6.1 Rechargeable pulse oximeter with power port and charging cable.

WARD LOCATION

The device and associated probes should be stored in a clean, dry, and secure area. When using the pulse oximeter, the device should be placed in a secure location to prevent drops and breakages. The device should never be placed inside a bed, cot or bassinet. All patient-related consumables should be stored in a clean, dry location. Keep cleaned probes separate from those waiting to be cleaned. Any cables should be loosely wrapped and secured, preventing sharp bends, pinches or kinks, which will decrease their lifetime.

DEVICE CALIBRATION

Manufacturers do not recommend calibration for any pulse oximeter components. Pulse oximeters automatically remove any variation or gain because the pulse oximeter algorithm uses a data ratio calculation to assess SpO₂.

DECOMMISSIONING

Assuming appropriate use and consistent maintenance, a pulse oximeter may last three years or longer. Reusable pulse oximeter probes may last up to six months or longer. Product developers define the probe cabling and connections to the sensor and probe head as the weakest parts of the device. Probes should be handled with care and users should be given consistent reminders about the correct use of the probe to extend its life.

Pulse oximeters are relatively low-cost; in such models, component breakages (i.e., control PCBs and LCDs) may cost more to repair than to replace. In those cases, decommissioning may be the most sensible option. A notable exception to this is the pulse oximeter probe, which is typically considered a long-lived consumable rather than a spare component. If the LCD or control PCB is still in good condition, these parts may be repurposed for other devices. Typically, the control PCB should only

be repurposed for devices of the same manufacturer and model, although components from the circuit board may be desoldered and repurposed independently.

PREVENTIVE MAINTENANCE

After Each Use

- ☐ Between patients, turn off the pulse oximeter. Wipe down the pulse oximeter housing and probe components with 70% alcohol. Be careful not to submerge or drip alcohol onto the pulse oximeter or any of its cables.
- ☐ Check all parts are present and connected.
- ☐ Check cables are not twisted and remove from service if any damage is visible.

See **Pulse Oximeter: Disinfection After Use** and **Alert 4.1** for more information.

Weekly

- ☐ Unplug, remove equipment cover (if applicable), clean and disinfect exterior surface with 70% alcohol
- ☐ Tighten any loose screws and check parts are fitted tightly.
- ☐ Check operation of all lights, indicators and visual displays.
- ☐ Check probe disconnection alarm.
- ☐ Document preventive maintenance actions taken.

Monthly

- ☐ Perform **Weekly** preventive maintenance steps.
- ☐ Test the pulse oximeter functionality:
 - ☐ Set up the device for use. Turn on the pulse oximeter. Connect probe and check for a red light.
 - ☐ Connect a clip probe and test readings on your finger for normal saturations (above 90%).
- ☐ Document preventive maintenance actions taken.

Quarterly

- ☐ Perform **Monthly** preventive maintenance steps.
- ☐ Assess the control PCB and battery terminals for any liquid, rust or electrical damage.
- ☐ Document preventive maintenance actions taken.

Annually

- ☐ Perform **Quarterly** preventive maintenance steps.
- ☐ Confirm supply of spare pulse oximeter probes and batteries are adequate to support estimated replacement for next year.
- ☐ Document preventive maintenance actions taken.

7 Troubleshooting & Repair

Biomedical engineers & technicians are responsible for providing rapid maintenance, troubleshooting & repair support for users.

PREPARE FOR REPAIR

ACCESSIBLE TOOLS	SPARE PARTS	DEVICE CHECKLIST
Digital multimeter Philips, star & flat head screwdrivers Needle-nosed pliers Wire strippers Allen keys Fine grain sandpaper	Probe Batteries Charger (if applicable) LCD screen Control PCB Buttons	<input type="checkbox"/> Pulse oximeter <input type="checkbox"/> Pulse oximeter probe <input type="checkbox"/> Charger (if applicable) <input type="checkbox"/> Probe adapter (if applicable)

TROUBLESHOOTING FAILURES

The pulse oximeter does not turn on.

Probable Cause:	Discharged or damaged batteries
Components to Check:	Battery level (if rechargeable) or voltage and physical condition Power switch physical integrity & continuity Control PCB physical & electrical integrity and continuity

The pulse oximeter turns on, but no trace is displayed.

Probable Cause:	Damaged or incompatible probe
Components to Check:	Probe physical condition, security & compatibility Control PCB physical & electrical integrity and continuity

The pulse oximeter turns on, but buttons do not respond to pressure.

Probable Cause:	Fluid damage
Components to Check:	Internal button physical condition

The pulse oximeter turns on, but takes time to stabilise the trace.

Probable Cause:	Movement or light interference
Components to Check:	Patient movement Measurement site perfusion, condition & cleanliness Environmental ambient light

Discoloured or black spots obstruct view of the display.

Probable Cause:	Damaged LCD
Components to Check:	LCD physical integrity

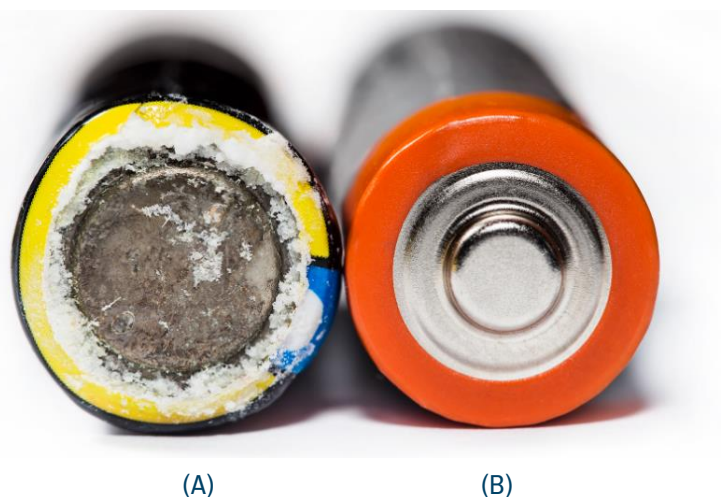
REPAIR & REPLACE

Where technically possible and not likely to obstruct clinical care, repairs may be made within the newborn care ward. Use discretion to determine if this is appropriate or if the device should be removed to the biomedical workshop for more testing or repair.

Testing, repairing & replacing the batteries

The pulse oximeter battery is typically responsible for powering all display, measurement and alarm functions. If the pulse oximeter is not turning on, the batteries should be visually assessed for rust or other physical damage. **(7.1)** Depending on the severity of the damage, rust or other build-up present on the battery terminals can be gently scraped off with very fine sandpaper or dissolved with an appropriate agent depending on battery type (vinegar for alkaline batteries and a paste of baking soda with water if acidic). **Wear goggles and rubber gloves throughout the cleaning process.**

Both the voltage across the battery terminals and the continuity of the wires from the battery to the control board should be tested and the battery or wires replaced if necessary. Specifications for battery voltage should be available in the manufacturer's service manual.



7.1 (A) Battery build-up over time (B) New battery.

Testing, repairing & replacing the probe

The pulse oximeter cabling and connections to the sensor and probe head are the weakest parts of the device. Remove the probe by holding the probe close to the base and gently extract it. **The probe cable should never be pulled on to remove the probe from the device.** Replace with a new probe and test SpO₂ levels. (7.2, 7.3)

Pulse oximeter probes are typically difficult to fully repair; best practice is to replace with a new probe when possible. Generic sensors are not always compatible with all pulse oximeters, even if the probe goes easily into the probe port. If a red light is showing on the probe sensor but no trace is displayed, the generic sensor may not be compatible with the pulse oximeter model. (7.4)



7.2 Remove probe by base connector.



7.3 Visually compare probe and probe port.



7.4 Not all probes will work with all pulse oximeters.

Testing & replacing control PCB and associated components

In most cases, if one element of the control PCB has malfunctioned, the entire control PCB should be replaced. Visually assess the PCB for burnt or damaged components. (7.5 – 7.9) Internal wiring continuity leading from the power supply to the control PCB and from the control PCB to various controls may also be assessed for replacement.

! Alert 7.1

Printed Circuit Boards (PCBs) contain components that are sensitive to electrostatic discharge (ESD) and can damage the board if not handled properly. As when handling any ESD-sensitive PCB, observe standard ESD safety procedures. **Pulse oximeter circuit boards are very small and easy to damage.** If repairs are needed on the circuit boards, perform all maintenance gently and with extreme caution to avoid unnecessary damage.



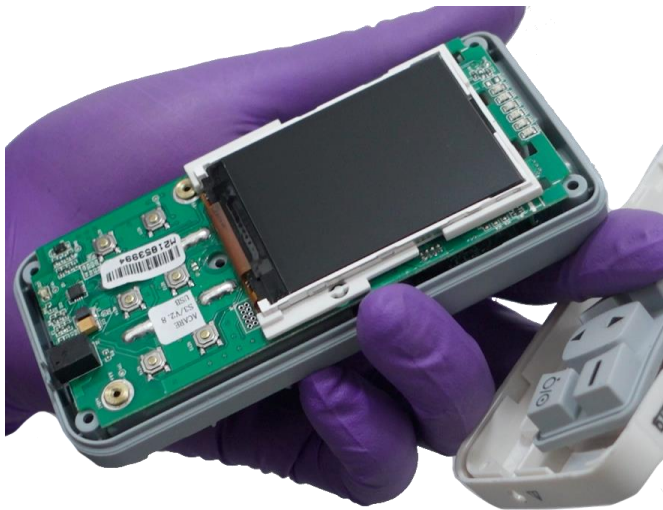
7.5 Unscrew the back of the pulse oximeter.



7.6 Gently pry off the back housing.



7.7 Open pulse oximeter to view components.



7.8 Remove key pad and assess components.



7.9 Gently pull up circuit boards to replace.

Assessing & repairing the buttons

Check that the device is disconnected from all sources of power before visually assessing the buttons for fluid damage internally. **(7.10, 7.11)** If fluid is present near or on the buttons or control PCB, wipe the fluid from the unit thoroughly using a non-abrasive cloth.

If the buttons are damaged beyond repair, contact the manufacturer to request a replacement part.



7.10 Confirm location on circuit board for key components.



7.11 Check the keys for water damage.

Assessing light & movement interference

If strong light (e.g., phototherapy, exam lights, or sunlight) is on a probe sensor, the light signal from the pulse oximeter probe may be drowned out by the stronger environmental light, leading to incorrect results. A cloth covering of the sensor site will protect it from bright light.

If a patient is particularly active, the contact point between the probe and the patient may move along the patient's skin. This movement provides an inconsistent measurement because it samples from various contact points in the skin, rather than remaining in the same contact point of tissue. This may cause the reading to be noisy or take time to stabilise. Some oximeters designed for newborns have purpose-built motion-cancelling algorithms to minimise false readings and alarms.

Testing & replacing the LCD

The LCD is typically damaged due to incorrect use, particularly when the user pushes with too much force on the screen. If the damaged areas do not hinder viewing or use of the display, the pulse oximeter may be used without significant issues. However, if the damaged areas prevent easy use, the LCD should be replaced. **(7.12)** Contact the manufacturer to request a replacement part specific to the pulse oximeter model. In some cases, the LCD is soldered on to the circuit board; in these instances, request a replacement board as necessary.



7.12 If the LCD is removable, gently prise off the housing and replace.

? Alert 7.2 Repurposing Parts

In some cases, parts on the unit may be replaced with a repurposed or recycled part from another piece of equipment being used for parts. **Repurposed parts should be considered with caution and guidance from the manufacturer to ensure specifications of the repurposed part is compatible with the equipment.** This includes spare parts and accessories that may not be compatible with multiple systems.

8 References

1. Bancalari, E. & Claure, N. Oxygenation Targets and Outcomes in Premature Infants. *JAMA* 309, 2161 (2013).
2. Cummings, J. J., Polin, R. A., & Committee on Fetus and Newborn. Oxygen Targeting in Extremely Low Birth Weight Infants. *Pediatrics* 138, e20161576 (2016).
3. Manja, V., Lakshminrusimha, S. & Cook, D. J. Oxygen Saturation Target Range for Extremely Preterm Infants: A Systematic Review and Meta-analysis. *JAMA Pediatr.* 169, 332 (2015).
4. Polin, R. A. & Bateman, D. Oxygen-Saturation Targets in Preterm Infants. *N. Engl. J. Med.* 368, 2141–2142 (2013).
5. Nitzan, M., Romem, A. & Koppel, R. Pulse oximetry: fundamentals and technology update. *Med. Devices Auckl. NZ* 7, 231–239 (2014).
6. *WHO-UNICEF technical specifications and guidance for oxygen therapy devices.* (World Health Organization and the United Nations Children’s Fund (UNICEF), 2019).
7. Curless MS, Ruparelia CS, Thompson E, and Trexler PA, eds. 2018. Infection Prevention and Control: Reference Manual for Health Care Facilities with Limited Resources. Jhpiego: Baltimore, MD.
8. World Health Organization, Regional Office for the Western Pacific, World Health Organization, & Regional Office for South-East Asia. *Practical guidelines for infection control in health care facilities.* (World Health Organization, Regional Office for Western Pacific ; World Health Organization, Regional Office for South-East Asia, 2004).
9. Sharma, G., Zaka, N. & Hailegebriel, T. Infection Prevention and Control at Neonatal Intensive Care Units. (2018).