



# Organization of a Neonatal Intensive Care Unit

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## Background

The organization of a neonatal intensive care unit (NICU) is essential for reducing the neonatal mortality and improving the quality of life among the survivors. During the past three decades, improvements in the diagnostic and therapeutic approaches in the care of high-risk infants have influenced their prognosis favorably. Unfortunately, many neonatal centers in the developing countries are unplanned and merely improvised. The pediatrician and nurse in charge of neonatal services should be taken into confidence during the planning stage so that the intensive care neonatal unit is based on their opinions for meeting the special needs of sick and small neonates. It is a welcome move that government of India has launched an initiative to establish special care newborn units (SCNUs) at district hospitals. The SCNU at the district hospital is envisaged to provide; (i) care at birth including resuscitation of asphyxiated newborns, (ii) management of sick newborns, (iii) referral and transport services for babies needing continuous positive airway pressure (CPAP), mechanical ventilation and major surgical intervention, (iv) postnatal care and immunization services and (v) follow-up of high-risk newborns.

Adequate space, availability of running water round-the-clock, centralized oxygen and suction facilities, maintenance of thermoneutral environment and ready availability of plenty of linen and disposables is mandatory to provide optimal level III newborn care. Facilities for prevention and management of common neonatal problems, viz. perinatal hypoxia, hypothermia, LBW babies, respiratory distress syndrome, septicemia, hyperbilirubinemia and life-threatening congenital malformations, should be established. The emphasis should be laid on developing a sound infrastructure to ensure safe delivery, promote asepsis,

provide warmth and adequate nutrition with human milk. The lop-sided enthusiasm to acquire sophisticated electronic gadgetry including ventilators, in the absence of basic infrastructural facilities, must be discouraged. At the present state of our development, level III or tertiary neonatal care should be established in a phased manner in regional centers selected on the basis of available infrastructure and professional expertise. Effective and optimal management of newborn babies at birth, prevention of hypothermia and bacterial infections and feeding of all babies with human milk should be ensured before establishing neonatal intensive care facilities. Intensive care of the newborn is highly cost-intensive and demands considerable inputs of staff, equipment and time. The philosophy of specialized conservative management of high-risk newborn babies should be fully exploited to bring down the neonatal mortality rate to less than 20 per 1000 live births before intensive care facilities are launched (Figure 1.1).



**Figure 1.1** NICU of All India Institute of Medical Sciences, New Delhi.



## PHYSICAL FACILITIES

### Space

The size of the unit is related to the expected population intended to be served. In India, about 15 to 20% of newborn babies need special care, depending upon the criteria for antenatal booking for confinement. In addition, if the center is to serve as a referral unit for the infants born outside the hospital (extramural babies), allowance should be made for additional physical facilities and space. In a maternity unit having 2,000 deliveries per year, facilities for special care of 6–8 high-risk infants should be available. Each infant should be provided with a minimum area of 100 sq. ft. or 10 M<sup>2</sup>. However, additional space would be needed to provide for special facilities as outlined below in the floor plan. There should be no compromise on space because its adequacy is crucial for reduction of nosocomial infections. Space should be allocated within the nursery complex for promotion of breastfeeding, expression of breast-milk and its storage, aseptic preparation of intravenous fluids and parenteral nutrients.

### Location

The neonatal unit should be located as close as possible to the labor rooms and obstetric operation theater, to facilitate prompt transfer of sick and high-risk infants. The presence of an elevator in close proximity is desirable for transport of outborn infants. In tropical countries, the nursery should not be located on the top floor of the hospital but there should be feasibility for the sunlight to peep into the nursery to enhance brightness and provide ultraviolet rays to augment asepsis.

### Nursery Design

The unit design may be in a square space or a single corridor-based rectangular unit. A split unit, i.e. on either side of the hospital corridor, should be avoided for ease of mobility and for prevention of infections. A unit design occupying one side of the corridor with a nurses control room in the center, from where all the babies can be viewed, is preferred (Figure 1.2). Apart from constant surveillance of all babies, the design should ensure minimal walking distance for the staff.

### Baby Care Area

The unit should be provided with areas and rooms for inborn or intramural babies, stepdown nursery, outborn or extramural babies, examination area, mother's area for breastfeeding and expression of

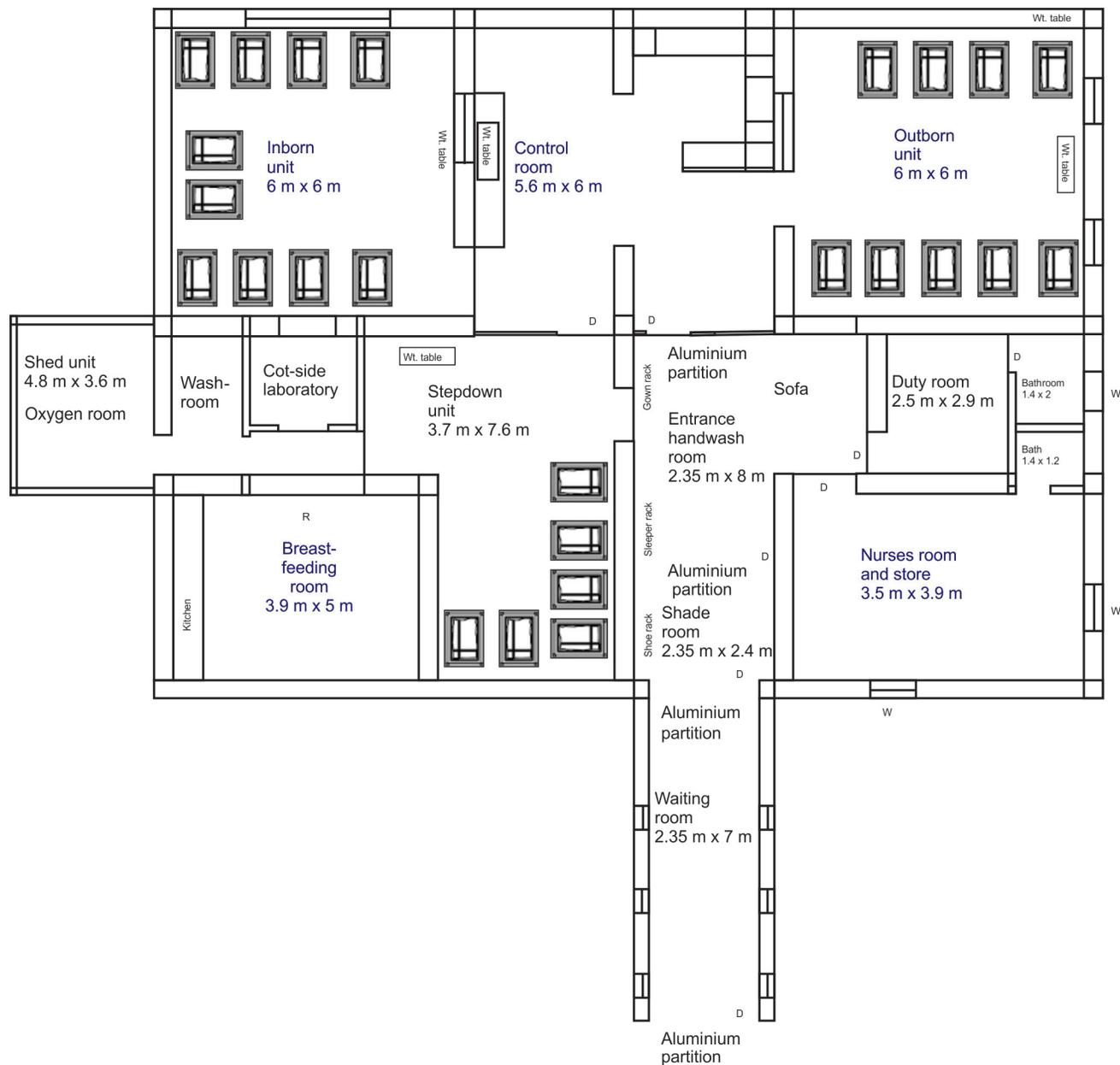
breast-milk, preparation of intravenous fluids and parenteral nutrients, nurses station and charting area. The floor and walls should be made of washable glazed or vitrified tiles and windows should have two layers of glass panes to ensure some measure of heat and sound insulation. The obviously infected infants with open sepsis (especially those with diarrhea and abscesses) should be isolated in a septic nursery, which should be located away from the NICU and manned by different nursing and resident staff. A large number of ancillary services are needed and should be designed and earmarked during the planning stage.

**Handwashing and gowning room** Handwashing and gowning facility should be located at the entrance. It should be provided with abundant space with self-closing doors. A positive air pressure should be maintained in the NICU so that corridor air does not enter the NICU. Street shoes are changed with nursery slippers, followed by handwashing and gowning. The use of mask is controversial and is best avoided. Hand-free elbow or foot-operated tap fitted in a handwashing sink with liquid soap dispenser is recommended. Sink should be made of porcelain or stainless steel. Pictorial handwashing instructions should be affixed on the wall next to the sink. Hands should be dried with single use or disposable paper napkins. Air dryers are not recommended due to risk of dissemination of microbes. Walls adjacent to the sink should be made of non-porous or non-absorbent material to prevent growth of molds. Sinks should not be provided with slabs or counter-tops which are a potent source of infection. The unit should be provided with 24-hour uninterrupted water supply by having dedicated overhead tank with a capacity of 1000–2000 liters.

**Examination area** A small comfortable room with examination table, comfortable seating, sufficient light, and warmth is needed for assessment of baby before admission to the nursery. The baby is cleaned and provided with nursery garments in this room.

**Mother area** The room should be provided with comfortable seating and privacy to the mother to breastfeed and express the breast-milk with the help of a lactation nurse.

**Handwashing stations** Handwashing sinks should be provided within 20 feet (6 meters) of every newborn bed. The sink should be large and deep (24" wide × 16" front-back and 10" deep) and made of porcelain or stainless steel and without any counter or shelf. Single use sterile cotton napkins or disposable paper napkins should be available for drying the hands. Alternatively, antiseptic



**Figure 1.2** The conceptual layout for a neonatal intensive care unit for 25 babies. *Adapted from tool kit for setting up special care neonatal unit, UNICEF.*

sanitizing solution (sterillium) can be used for disinfection of hands in-between the babies.

**Preparation of intravenous fluids** A separate area should be earmarked and provided with a laminar flow system for preparation of intravenous fluids, parenteral nutritional formulations, enteral feeds and medications. Boiling and autoclaving facilities should be available adjacent to this area.

**Nurses station** Nursing station and charting area for nurses and residents should be located in a central area from where all the babies can be observed. Newborn

charts, hospital forms, computer terminals, telephone lines should be located in this area. It is preferable to use electronic medical recording of clinical notes and retrieval of laboratory reports.

**Clean utility and soiled utility holding rooms** There should be enough space for stocking clean utility items and sterile disposables, and for disposal of dirty linen and contaminated disposables. Built-in wall wooden cabinets with foldable covers are useful for stacking purposes. The ventilation system in the soiled utility or holding room should be engineered to have negative



air pressure with all air being exhausted to the outside. The soiled utility room should be so located that it enables removal of soiled material without passing through the baby care area.

**Staff rooms** Space should be provided within the unit to meet the professional, personal and administrative needs of resident staff on duty. A comfortable room with intercom, telephone and computer terminal and WC facilities is mandatory. Nurse's change room is required for changing from street clothes to a smart shirt and trouser dress stipulated by the NICU.

**Growing nursery** A separate bay in the lying-in ward should be earmarked for transitional care of high-risk babies by their mothers before they are discharged from the hospital. The entry of visitors to this area should be restricted and it should be kept adequately warm. Facilities for monitoring sepsis and weighing the babies should be available in the transitional care room (TCR) or growing nursery (GN). The growing nursery is used with advantage for educating the mothers in child care activities and promoting the practice of exclusive breastfeeding.

### Ventilation

Effective air ventilation of nursery is essential to reduce nosocomial infections. The most satisfactory ventilation is achieved with laminar airflow system which is rather expensive. When centralized air-conditioning is used, minimum of 12 changes of room air per hour are recommended. There should be no draughts of air on and near the newborn beds. The air-conditioning ducts must be provided with millipore filters ( $0.5 \mu$ ) to restrict the passage of microbes. A simple method to achieve satisfactory ventilation consists of provision of exhaust fan in a reverse direction near the ceiling for input of fresh uncontaminated air and fixation of another exhaust fan in the conventional manner near the floor for air exit. A constant positive air pressure should be maintained in the nursery so that contaminated air from the corridors does not gain access into the nursery. The use of chemical air disinfection and ultraviolet lamps are no more recommended.

### Lighting

The nursery must be well-illuminated and painted white or slightly off-white to permit prompt and early detection of jaundice and cyanosis. It is best achieved by cool white fluorescent tubes or LED (light-emitting diodes) to provide at least 100 foot-candle, shadow-free illumination at the infant's level. The number and exact location of fixtures can be worked out taking into

account size of the nursery, height of the ceiling, and availability or otherwise of sunlight. Spot illumination for various procedures can be provided by a portable angle-poise lamp having two 15 watt fluorescent bulbs which when held at a distance of about one foot from the infant, produce about 100 feet-candle intensity of light. Most open care systems are equipped with in-built source of overhead spot lights. In places where electrical failure is frequent and prolonged, the electrical system of the nursery complex must be attached to an auto-mode generator. Exposure of preterm babies to strong light has been incriminated as a risk factor for the development of retinopathy of prematurity. The nursery light should be dimmed at night to simulate day-night pattern to promote hormonal surge and growth of babies. Bedside lights with dimmer switches should be provided to create specialized micro-environment for each baby.

### Environmental Temperature and Humidity

The temperature of the nursery complex must be maintained between  $26-28^{\circ}\text{C}$  ( $78.8-82.4^{\circ}\text{F}$ ) in order to minimize effects of thermal stress on the babies. This is best achieved by centralized air-conditioning having temperature control knobs in the nursery. The air movement should be so designed that draught is minimized. In places where air-conditioning is not feasible, room temperature can be reasonably well-maintained in winter by use of radiant heaters and hot air blowers. Portable radiant heater, infrared lamp or bakery bulb can be used to provide additional source of heat to an individual infant. The external windows of nursery should be glazed to minimize heat gain and heat loss and baby beds should be located at least 2 feet (0.6 meter) away from the wall or window. In most parts of India, relative humidity averages above 50%, which is quite satisfactory for routine needs of newborn babies. Humidity level can be raised for preterm babies nursed in an incubator. High and effective humidity level is useful to reduce insensible water loss but is associated with increased risk of nosocomial infection.

### Acoustic Characteristics

The ventilation system, incubators, air compressors, suction pumps and many other devices used in the nursery produce noise. Sound intensity in the nursery should not exceed 75 dB to protect hearing of nursery personnel and infants. Excessive noise may lead to hearing loss, physiological and behavioral disturbances, such as sleep disturbances, startles and crying episodes, hypoxia, tachycardia and increased intracranial pressure. The fabrication and redesigning of nursery



equipment should take into account the desirability of minimizing noise by dampening the sounds by acoustic or other means. It is desirable to have effective soundproofing of ceilings, walls, doors and floor when a NICU is designed. Telephone rings and equipment alarms should be replaced by blinking lights. Instead of air compressors, centralized sources of compressed air, oxygen and suction should be provided. Decibel meters should be installed to monitor sound levels in the nursery. The beneficial and soothing effects of meaningful sounds, such as gentle music or recordings of parent voice, should be harnessed to provide physiologic stability to the babies.

### Handling and Social Contacts

Excessive and rough handling of delicate newborn babies is associated with several adverse physiological consequences, such as excessive crying, sleep disturbances, tachycardia or bradycardia, hypoxia and rise in blood pressure and intracranial pressure. Handling should be gentle and kept to the barest minimum without compromising care. Soothing words, gentle stroking and rocking should be practised after a painful procedure. Gentle caressing, cuddling and touching by the mother are desirable to provide comfort and confidence to the baby and aid the process of healing. Infants should be exposed to gentle and soothing tactile, kinesthetic, vestibular, motor, auditory and visual experiences to provide opportunities for early learning and improvement in behavior. Parents should be allowed unrestricted entry to the nursery to provide these useful sensorimotor stimuli. It enhances the process of bonding between the baby and the family.

### Communication System

The nursery complex should be provided with an intercom system so that additional person can be called for help in case of emergency without leaving the sick infant. A direct line external telephone is mandatory so that parents have an easy access to inquire about welfare of their infants and in turn they can be readily contacted whenever needed. Mobile phones should not be used near the vicinity of the nursery because the electromagnetic waves are likely to interfere with the functioning of the electronic equipment. The family should be kept constantly informed about the condition of their baby including therapeutic interventions being given. They should be given emotional support and pragmatic view of the likely outcome.

### Electrical Outlets

There should be adequate number (8–12 electrical points at the height of 4–5 feet) of 5 amperes and

15 amperes electrical points attached to a common ground. Each infant must be provided with at least 8 electrical outlets, 4 should be 5 amperes and another 4 of 15 amperes. The use of adapters and extension boards should be discouraged. The electrical equipment used in the nursery must be checked at least once a month for leakage of current and adequacy of grounding. If possible, special fittings with safety devices should be installed. The unit should have round-the-clock uninterrupted servo-stabilized power supply. There should be round-the-clock power back-up including provision of UPS system for the sensitive equipment.

### PERSONNEL

It is important, that while allocating nursing, medical and paramedical staff to the hospital, the needs of the neonatal unit are not ignored. It is unfortunate that newborn babies are not counted as patients requiring nursing and medical care while expressing the bed strength of a hospital. The census of the hospital bed is administratively based on dieted beds. In fact, the situation is paradoxical because the neonates need rather specialized and sophisticated nursing and medical care. Therefore, the highest priority in the organization of the NICU is the availability of sufficient number of adequately trained personnel especially the nurses. The survival of newborn babies depends upon the availability of specially trained nurses. The Nursing Council of India has not outlined any special guidelines for this purpose. It has been recommended by the American Academy of Pediatrics that one nurse is needed to offer special or intermediate nursing care to 3 babies or intensive care to one infant. In countries where monitoring devices are not routinely available, relatively larger number of nurses are necessary for undertaking manual monitoring. It is generally not appreciated by the hospital administrators that a considerable time of the nurse is spent in rigorous housekeeping rituals to maintain asepsis in the nursery. The frequent toilet care, expression of breast-milk, formula preparation and feeding are time consuming and unassisted by any attendant. Whenever adequate number of nurses are not available, these rituals are compromised resulting in inadequacy of feeding and outbreak of infection in the nursery. The nursery complex must, therefore, be considered as an independent nursing unit under the charge of a fully qualified nursing sister.

The National Neonatology Forum of India has recommended that at least one trained nurse should be allocated to provide coverage to four babies in the special care neonatal unit. The allowance should be kept



for additional 25% staff to provide for the exigencies of day off and leave. Therefore, for a 8-bedded SCNU or level II neonatal unit, eight nurses should be sanctioned to ensure availability of two nurses in each shift along with one additional sister incharge in the morning shift. In a NICU, the overall allocation of nurses should be one nurse for two babies, i.e. 16 nurses for 8-bedded unit. The continuity of service can be maintained, if at least 50% of the nurses are rather permanent and not transferred frequently as is the usual practice in general hospitals. There must be equal distribution of nurses in the three duty shifts during 24 hours. The nurses must be imparted continuing in-service training in the art of neonatal nursing and preventive maintenance of a variety of electronic equipment used in the NICU. They should participate in the monthly perinatal morbidity and mortality meetings. It is desirable to have services of public health nurses and social workers for follow-up and home care of low birth weight babies after their discharge from the hospital.

A pediatrician specially trained in the care of newborn babies should devote his full time to improve the existing standards of neonatal special care services in the country. The unit must also have an independent senior resident and one junior resident round-the-clock for every 4 babies requiring intensive care. The resident doctors must work in these units for at least 3 months to maintain continuity of medical care. All deliveries in the hospital should preferably be attended by a physician trained in the care of newborn. A laboratory technician should be available to operate bilirubinometer, glucometer, microcentrifuge, CRP kits and blood gas analyzer. A biomedical technician or a link person is essential to maintain a liaison with suppliers of equipment to ensure their smooth functioning, prevent breakdowns and reduce the downtime. The resident staff and nurses working in the NICU must be trained to properly handle and use the equipment. When ventilatory facilities are established, respiratory therapist is a useful member of the neonatal team to monitor ventilatory settings, provide tracheal suctioning and chest physiotherapy. A pediatric pathologist, who is specially trained for conducting and interpreting neonatal autopsies, is desirable to complement the functioning of the neonatal team.

## EQUIPMENT

During the last 2–3 decades, a large number of monitoring devices for diagnostic and therapeutic use for the high-risk newborn infants have been developed.

These have considerably improved the monitoring and intact survival of high-risk neonates. Several basic prerequisites must be fulfilled before any center invests in purchase of expensive equipment involving foreign exchange. The fundamental needs of the unit are availability of adequate space, round-the-clock water supply, freedom from congestion and presence of a sufficient number of adequately trained nurses. A reasonable level of asepsis must be achieved and facilities for maintaining thermoneutral environment should be established. The feeding of babies should be associated with minimal risk of aspiration.

Acquisition of new equipment does not necessarily ensure better services and outcome. *Machines cannot replace men. The best monitors with us are dedicated nurses and resident doctors involved in the care of newborn babies with their observational skills sharpened by experience.* Therefore, they need continued in-service training, teaching and encouragement for obtaining the best results. In view of the exorbitant cost of imported equipment and problems faced in their maintenance, there is a constant need to promote “make in India” concept for indigenous fabrication of equipment required for neonatal care.

The maintenance of the existing equipment in proper working condition is more important than acquiring new and sophisticated gadgets. Before placing an order, check with existent consumer/s regarding reliability of the equipment and quality of after sales service provided by the local dealer. The supplier must install the equipment and provide training to the staff for proper use and maintenance of the equipment. Date of installation and expiry of warranty period should be recorded. After expiry of mandatory warranty period, you should enter into an annual maintenance contract with the local dealer for preventive maintenance and emergency repairs in the event of breakdowns. In case of sophisticated and expensive equipment, a counter-guarantee of service should also be taken from the foreign principals. Inventory of spares should be maintained and essential spares should be purchased and kept in stock while ordering new equipment. Photocopies of working and service manuals should be available in the NICU while original documents should be kept in a safe custody. Maintain a log book containing postal and e-mail addresses, telephone and fax numbers of local dealers and suppliers of equipment. When telephonic or e-mail complaints are not heeded by the local supplier, you should send a written complaint and endorse a copy to the foreign principals.



### Preventive Maintenance and Emergency Repairs

After-sales technical services including annual maintenance contract (AMC) should be a mandatory requirement at the time of purchase of the equipment. At the time of installation, the supplier should provide technical training, hands-on training for clinical use of the equipment and its proper maintenance to the nurses and resident doctors. A qualified in-house biomedical technician should be available to maintain an inventory of equipment and spares, ensure optimal preventive maintenance and take prompt action to call the service engineer to ensure maximum uptime of the life-saving medical equipment. The in-house technician should have up-to-date information regarding the proper use of the equipment, should be able to undertake first-line corrective intervention that does not require any spare parts and when required he should be able to report correctly the nature of technical malfunctioning of the equipment to the on-call service engineer of the company.

The objectives of preventive maintenance include that the equipment should be functional most of the time and should operate with accuracy, efficiency and safety. The maintenance engineer should undertake at least two technical visits per year to check the wear and tear, and performance of the device as per manufacturers technical check list. The equipment should be cleaned and defective components replaced by spare parts. He should interact with in-house technician and end-users to provide necessary guidance for correct use of the equipment to ensure effective preventive maintenance and upkeep.

Despite careful use of the equipment, the average lifetime of most electronic equipment is about 5–7 years. In the event of breakdown, when contacted the service engineer should report to the NICU without delay to ensure that the downtime of the equipment is minimum. In case the device cannot be repaired on-site and the machine is taken to the workshop, a replacement model should be provided by the company for the period of the repair.

The equipment listed and described below are by and large arranged in the order of their usefulness and priority. *The maintenance of existing equipment in proper working condition is more important than acquiring additional gadgets.*

### Resuscitation Equipment

The equipments needed for resuscitation of an asphyxiated baby at birth are discussed in detail in

Chapter 4. Emergency tray should be available in each infant care room of NICU containing Ambu bag and mask, infant laryngoscope, tracheal tubes of different sizes, sterile suction catheters, oral mucus suction traps, and emergency drugs.

### Bag and Mask Resuscitator

Self-inflating bag of 250–750 mL capacity is ideal for resuscitation of a newborn baby. It remains inflated at all times without any compressed gas source. There are four components of self-inflating bag, i.e. air inlet, oxygen inlet, patient outlet and valve assembly (Figure 1.3). It should be provided with a pop-off valve or with a facility to attach a pressure gauge. An oxygen reservoir in the form of a corrugated tube or rubber bladder, helps to increase the oxygen concentration to 90 to 100%. When self-inflating bag is used without an oxygen reservoir, it delivers 40–60% oxygen because room air enters the bag with each inflation. A one-way valve allows delivery of oxygen at the outlet when bag is squeezed but closes as soon as the bag is released so that the exhaled air cannot re-enter the bag. A peep valve can be attached to the valve assembly to deliver required PEEP. A pressure gauge can be attached to a small hole or projection located near the patient outlet. The gauge allows the person using the bag to control the pressure of air or oxygen being delivered to the baby. The self-inflating bag cannot be used for providing free-flow oxygen to the baby unless it is equipped with a closed bladder reservoir. The silicone rubber bags of Laerdal make are more sturdy and can withstand autoclaving and cleaning with antiseptic solutions. Face masks (size 0, 1 and 2) should be rigid with a cushioned rim to form a tight air-seal fit on the face enclosing the mouth and nostrils. Anatomical shaped masks are avoided due to the potential risk of causing local trauma due to pressure. Indigenously manufactured bags and masks are highly unsatisfactory due to poor quality of rubber, lack of oxygen inlet, absence of any safety features and loss of re-expansion capabilities of the bag.

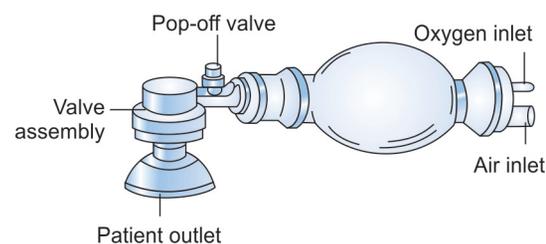


Figure 1.3 The components of self-inflating bag.



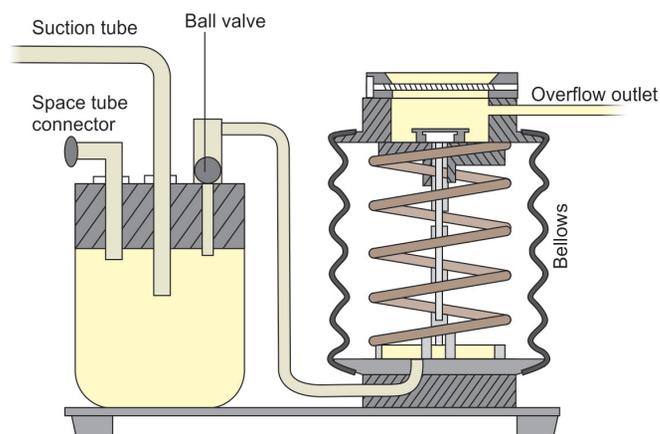
**Figure 1.4** Resuscitator for receiving babies at birth. Note the stop clock which is useful to time the events during resuscitation.

A resuscitator trolley equipped with radiant warmer, timer, electrical suction, observation light and manual assisted ventilation facilities is an essential equipment for the delivery room (Figure 1.4). In-built pulse oximeter is extremely useful to monitor heart rate and oxygen saturation.

### Oxygen and Suction Facilities

A centralized source of oxygen, compressed air and suction outlet consoles (50 psi) affixed on the walls is ideal. By mixing variable quantities of compressed air and oxygen, one can obtain oxygen concentrations ranging between 25% and 100%.

De Lee trap for a single use self-oral suction with 12 Fr catheter should be avoided because of potential risk of transmission of HIV infection. A soft plastic catheter or nozzle with a suction bulb is a good alternative but difficult to clean. Suction machines using recoil springs are bulky and complex to operate and difficult to clean. A foot-operated suction machine is useful in rural health care facilities because of non-availability or erratic power supply (Figure 1.5). In hospitals, centralized suction, venturi suction and electrical suction machines are used. The suction



**Figure 1.5** Diagrammatic sketch of a foot-operated suction machine.

pressure is regulated with a pressure dial. Facility should be available for intermittent suction because continuous suction may cause bradycardia and mucosal damage. The suction pressure should be limited to 60–80 cm H<sub>2</sub>O (1.0 mm Hg = 1.3 cm H<sub>2</sub>O). Slow suction devices are used for continuous suction of chest cavity and upper pouch of infants with esophageal atresia.

### Catheters, Syringes and Needles

Nasogastric polyethylene feeding tubes (Fr 5, 6 and 8), suction catheters (Fr 10 and 12), umbilical vein catheters, small-vein infusion sets (G 23), medicaths (neoflon), and exchange transfusion sets are now freely available in India at a reasonable cost. They are prepacked sterile by a process of gamma-irradiation. These should not be reused after boiling. As relatively small volume of parenteral medications are needed for low birth weight babies, it is desirable to use tuberculin or insulin syringes for injections to ensure ease and accuracy of administration. Only single-use syringes and needles should be used. The availability of liberal supplies of disposables is crucial for reduction of nosocomial infections.

### Feeding Equipment

Glass or stainless steel bowls of adequate size (120 mL capacity) should be available in the nursery for collection of expressed breast-milk, mixing and preparing the formula. A hot air autoclaving oven or a pressure sterilizer should be provided for autoclaving feeding equipment. Storage facility, like a refrigerator, should be available in the nursery. The formula room should be equipped with working shelves having laminated plastic surfaces or preferably these should be made of stainless steel so that they can be easily washed and cleaned.



### Laminar Flow System

The laminar flow system is useful for safe and aseptic formulation and mixing of drugs, parenteral fluids and nutrients. It is equipped with high efficiency particulate aggregate (HEPA) filter to block entry of bacteria, a blower and plenum. HEPA filters are effective in trapping 99.97% of all the particles of  $>0.3 \mu$  size including dust and bacterial pathogens. Two types of systems are available. In a vertical type system, the air flows from above downwards and it is recommended for use in the NICU. The horizontal flow type system is used for tissue culture and microbiologic techniques. Ultraviolet light source in the chamber is kept on for 30 minutes before use to make the area of operation free of bacteria. The vertical flow of bacteria-free filtered air maintains a positive pressure of 15 mm Hg to prevent entry of contaminated air into the chamber. Strict asepsis should be ensured by wearing mask, sterile gown and disposable gloves while operating the laminar flow system. The critical work area and accessible surfaces should be disinfected with bacillocid or 70% isopropyl alcohol.

### Weighing Machine

Accurate weight record of babies is a sensitive index of their wellbeing and availability of a sturdy and reliable weighing machine fulfills a fundamental need. A sensitive beam-type weighing scale with a precision of  $\pm 10$  g is a useful equipment in the nursery. It must be calibrated frequently against standard one kilogram weight. The chances of cross-infection should be minimized by using a sterile paper or a towel over the pan before weighing each infant. Electronic weighing machine (resolution either  $\pm 5$  g or  $\pm 1$  g) with a digital read-out though expensive is desirable for sake of convenience and accuracy (Figure 1.6). Availability of



**Figure 1.6** Electronic weighing scale with an accuracy of  $\pm 1.0$  g.

a reliable and sensitive electronic weighing scale is more useful and desirable than acquiring a ventilator which is kept as a show piece in the nursery.

### Bassinets

A variety of bassinets are available for routine use in the nursery. It is desirable to use bassinets, which can be easily cleaned and are equipped with a locker and head tilting mechanism (Figure 1.7). The locker can be used to hold the supplies of an individual baby, such as diapers, frocks, sterile gauze, cotton, thermometer, feeding equipment, drugs, etc.

Plastic plexiglass or fiberglass bassinets with relatively low walls and placed at a convenient height are desirable for ease of observation and examination of the infant. They can be easily cleaned and disinfected by antiseptic solutions. Alcohol or organic solvents should not be used to clean the plastic or plexiglass material due to risk of opacification.

### Incubators

The incubators are essential to provide an ideal micro-environment for high-risk babies. About one-third of nursery beds should comprise of incubators. The main functions of an incubator are isolation, maintenance of thermoneutral ambient temperature, desired humidity and administration of oxygen. It is desirable to nurse extremely low birth weight ( $<1000$  g) stable babies in the incubator. The sensory stimuli, like light, sound, touch and pain, should be kept to the barest minimum without compromising the quality of care. It is essential



**Figure 1.7** Plexiglass bassinets for keeping stable babies. They are aesthetic and easy to clean.



that an incubator should not interfere with observation of infant, should offer easy access to the baby and be readily cleanable. Even when sterile water is used in the humidity tank, incubators are a potential source of infection. The water in the humidity tank should be changed daily and 1–2 mL of glacial acetic acid or vinegar should be added to prevent bacterial colonization. Most centers are now using incubators without adding any water in the humidity chamber, while in some countries incubators are used to provide 100% humidity akin to in-utero environment.

The incubator may be of portable type for transport of sick babies or stationed in the nursery. The open box type (Armstrong) incubators are incapable of maintaining thermoneutrality due to alterations in the temperature when lid is opened. They are equipped with an inefficient thermostat and do not provide for entry of filtered air in the incubator. The intensive care or closed type (isolette) incubators are equipped with portholes for access to the infant (Figure 1.8). The front panel can also be opened and bassinet can be pulled out for unhindered access to the infant for examination and various procedures. These incubators are equipped with an air pump for circulation of filtered air for uniform distribution of heat throughout the incubator. They are also provided with partitioned circuit which allows for gradual changes in heat current as opposed to conventional on-off thermostat. A double wall incubator is preferred because radiant heat loss is reduced by 50%. A servo-control system is ideal for automatic adjustments in the ambient temperature to keep the infant homeothermic. Skin sensor or thermocouple is affixed to the abdominal skin over the liver area or right hypochondrium and incubator is set for maintenance of skin temperature at 36.5°C. The skin sensor feeds the information regarding temperature of the baby to the thermostat which automatically

regulates the output of heat to maintain the desired skin temperature. Infants nursed under servo mode should be watched to ensure that skin probe is in place. If skin probe inadvertently gets dislodged, infant may get overheated because ambient temperature would approach the set temperature of 36.5°C. They should be provided with in-built audio and visual alarms for set temperature, high body temperature, air flow, probe or sensor failure, etc. When fever develops in a baby nursed on skin servo mode, there will be repeated activation of alarm unless baby is shifted to manual mode. The built-in heater output monitor provides information regarding the amount of heat generated by the incubator warmer to keep the infant homeothermic. When heater output reading is minimal or nil, it suggests that infant is capable of generating enough metabolic heat to keep himself warm and he can be taken out of the incubator and nursed in an open cot.

### Radiant Warmer/Open Care System

During various procedures, the infant loses body temperature, unless he is kept warm by use of radiant heat warmer. A portable heat lamp with two 150 watt white ordinary or bakery bulbs or infrared bulb fixed on the wall about 2 to 3 feet above the level of table or trolley can serve the purpose in a rural setting. The infrared heat is preferable because it directly warms the subject without affecting the temperature of intervening environment.

Open care systems which are equipped with an overhead radiant warmer and skin thermister or thermocouple with servo-control are the most useful and popular equipment. When an overhead radiant warmer is intended to be used for a prolonged period, it should be combined with a skin sensor and a servo-control system. They are equipped with a narrow band proportional heat controllers which can rapidly cycle up and down the temperature. They are provided with audio and visual alarms for high and low temperature and heater output. Recently, talking warmers have been introduced which provide verbal warning to the nurses regarding low temperature, high temperature and out of reach temperature. The steps followed in using an open care system are summarized in Box 1.1. Unless baby is extremely small or gravely sick, open care system is preferable over an intensive care incubator because of easy access to the infant and less chances of nosocomial infection. Skin probe is applied over the liver area in the epigastrium or right hypochondrium, and shielded with a foil-covered foam adhesive pad. When a baby is nursed prone, skin probe is applied over the flank. The probe should not be allowed to come



**Figure 1.8** Intensive care double-walled incubator. It is provided with portholes and circulation of filtered air.



in contact with the bed. When probe is dislodged, it may lead to hyperthermia in the baby. These units also have a provision for overhead light source and phototherapy unit and are most suitable for undertaking any prolonged procedure, like assisted ventilation, exchange blood transfusion or surgery (Figures 1.9 and 1.10). Babies nursed in the open care

#### BOX 1.1 Steps for using open care system

- Switch on the unit.
- Select manual mode with heater output of 100% for 10–15 minutes for rapid warming of the bassinet covered with linen.
- Select servo mode to maintain skin temperature of the baby at 36.5°C.
- The skin probe site (right hypochondrium in a supine baby and flank when baby is nursed prone) is prepared by using surgical spirit.
- Fix the probe with adhesive tape and cover it with a reflective pad.
- Ensure that the skin sensor is kept affixed to baby's skin at all times.
- When a hypothermic baby needs to be rapidly warmed, select the manual mode and the desired heater output.
- Record baby's axillary temperature after 30 minutes and then 2 hourly.
- Respond to alarm immediately, identify the fault and rectify it.



**Figure 1.9** Open care system. It is equipped with overhead heat and light source along with servo-control facility.



**Figure 1.10** Premature infant in an open care system on ventilator and multichannel vital sign monitor.

system have excessive evaporative fluid losses and have significantly higher metabolic rate compared to babies kept in the incubator. After stabilization of the baby kept in the open care system, it is preferable to cover the baby with clothes or thin polythene sheet to reduce evaporative fluid losses. Application of sterile liquid paraffin or non-irritating oil on the skin is associated with reduced evaporative losses from skin.

#### Therapeutic Cooling Devices

High technology whole baby cooling devices (Blanketrol, Tecotherm Neo, Meditherm) are equipped both for cooling and rewarming the baby by virtue of a heater, a compressor, water circulating pump and a microprocessor board. The baby is placed on a blanket which is designed to circulate cold or warm distilled water which is pumped from the unit. The equipment functions in three modes, manual mode, automatic or servo mode and monitor only mode. The water hoses of the blanket are connected to the cooling unit.

The manual control mode is used to pre-cool the blanket by circulating sterile or distilled water cooled to the set temperature of 5°C. The baby (<6 hours of age) fulfilling the inclusion criteria for whole body cooling, is placed in a supine position on the blanket to ensure that complete body including occiput is touching the blanket (Figure 1.11). The radiant warmer or any other source of exogenous heat should be put off.



**Figure 1.11** Infant with grade 3 HIE being nursed on a cooling blanket and attached with various monitoring devices.

A disposable temperature steri-probe is placed in the esophagus or rectum to automatically maintain core temperature of the baby to 33.5°C. Esophageal probe is inserted through the nose and placed in the lower third of esophagus and securely taped. During automatic or servo mode, the unit maintains the set temperature of the baby either by cooling or warming the water circulating in the blanket. After the blanket is completely filled with water, check and maintain the level of sterile water in the reservoir at the desired level. Selective head cooling devices (olympic cool cap) are available which are associated with reduced immediate adverse effects because core body temperature is maintained at a safe level by use of a radiant warmer. However, selective head cooling is less effective in improving survival and reducing the risk of neuromotor disability in neonates with severe hypoxic-ischemic encephalopathy (HIE).

The infant is provided with state-of-the-art NICU care by monitoring vital signs, biochemical parameters, maintenance of fluids and electrolytes, blood gases and acid-base parameters with the help of assisted ventilation, high-frequency oscillations (HFO) and inhaled nitric oxide (iNO). Antibiotics should be given as per the protocol of the NICU. The neurologic status is checked clinically, with the help of an aEEG and neurosonography. The infant is nursed on the cooling blanket for 72 hours and then gradually warmed by raising set temperature by 0.5°C every hour to achieve skin temperature of 36.5°C in a period of about 6 hours.

### Thermometers

Low reading (30–40°C) rectal thermometer is essential to assess the severity of hypothermia. The severity of

hypothermia in small babies may be overlooked, if only conventional thermometers are used. Electronic or tele thermometers with skin sensors or rectal probes with an accuracy of  $\pm 0.1^\circ\text{C}$  are ideal for continuous atraumatic monitoring of body temperature. These temperature monitors are also equipped with acoustic and visual alarms set at a desired low and high temperature. Simultaneous monitoring of core and toe temperature can provide useful information regarding state of peripheral perfusion. When a baby gets overheated in the incubator, both core and peripheral skin temperature rises while in an infant with circulatory failure, peripheral skin temperature may be more than 1°C lower than core temperature. This offers quantitation and objectivity to the time honored clinical observation of finding warm trunk and cold extremities in infants with septic shock. Cold extremities, in the absence of shock, suggests that the baby is under cold stress and expending extra oxygen and calories for metabolic thermogenesis and thus compromising the weight gain or growth of the baby.

### Oxygen Concentrator

Portable oxygen cylinders are expensive and not readily available in a district hospital or community health center. Oxygen concentrators are being indigenously manufactured and they work both on a battery and mains. The atmospheric air is passed through a chemical zeolite (aluminium silicate) which absorbs all gases except oxygen. It can increase the concentration of oxygen in the air from 21% to about 90%. The oxygen sensor device (OSD) shows a green signal when oxygen concentration in the outlet exceed 90%. It is possible to treat simultaneously up to four infants (flow rate 0.5–1.0 liter/min) at a time by using an oxygen flow-splitting device. The equipment is provided with four filters to eliminate dust, humidity and bacteria (Figure 1.12). Depending upon the flow rate, various concentrations of oxygen can be delivered to the patient. Oxygen-air blender with an oxygen analyzer can be interposed to deliver a precise concentration of  $\text{FiO}_2$  but it considerably enhances the price of the device. Oxygen must be warmed (36.0–36.5°C) and humidified before administration to the baby. Oxygen concentrators are cost-effective and promoted by WHO in developing countries. The unit cost is high (around INR 50,000–00) but recurrent costs are low. They are useful in domiciliary practice for administration of oxygen to preterm neonates with chronic lung disease (CLD) and children with chronic interstitial lung disease.



Figure 1.12 Prototype of oxygen concentrator.

### Oxygen Head Box (Oxihood)

A square-shaped box made of transparent plastic or perspex which can enclose the head of the infant is useful for administration of higher concentration of oxygen. The box should be made of unbreakable material molded as a single piece without any joints. It can be used whether the baby is nursed in an open cot or incubator. It should be provided with an adjustable neck port or flexible occluding collar to create an effective seal to prevent free entry of environmental air. The oxygen concentrations which are likely to be achieved with different flow rates should be printed on the box.

### Oxygen Analyzer

This is useful for monitoring ambient oxygen concentration in order to protect the infant against oxygen toxicity. It helps in regulating the flow rate of oxygen so that desired concentration of oxygen is delivered to the infant depending upon his clinical condition and oxygen requirements. The Beckman's paramagnetic oxygen analyzer of earlier days has been replaced by newer oxygen sensors which operate on galvanic cell principle. The electric current generated between two electrodes is proportional to the partial pressure of oxygen. Cathode is gold plated while anode is made of lead and filled with potassium hydroxide. The newer oxygen analyzers provide continuous digital display of oxygen concentration and trigger off audiovisual warning signal when environmental concentration of oxygen falls or rises beyond the safety levels (Figure 1.13). The instrument is calibrated by checking the oxygen concen-

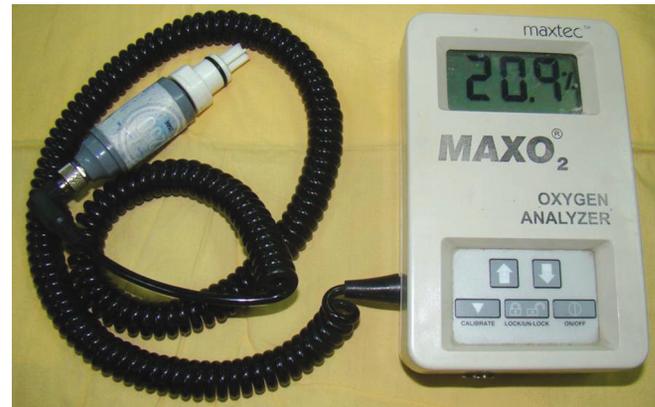


Figure 1.13 Oxygen monitor. It provides continuous digital display of ambient oxygen concentration.

tration of room air which is kept constant at 21%. The sensor life is about 9 months only and would need replacement once a year.

### Perspex Heat Shield

Heat shield made of perspex or transparent plexiglass measuring 18" × 10" × 8" in a dome shape is a very simple and useful device to reduce the heat loss by radiation and evaporation. When a sick infant with respiratory distress is nursed naked in the incubator, he must be enclosed in the perspex heat shield to limit fluctuations in his body temperature. It reduces insensible water loss by about 25%. Based on this analogy, the currently available intensive care incubators are double-walled, which are credited to reduce radiant heat loss by 50%.

### Transilluminator

It is a useful, cheap, non-invasive device for point-of-care use in a number of situations in NICU. Fiberoptic light source is used to provide up to 12,000 candles with a halogen quartz lamp, LED light source or xenon arc. The shorter wavelengths (up to 470 nm) of visible light which produce heat are filtered out to provide "cold light" at the tip of the cable. The efficacy of transillumination is enhanced by competence of the operator, intensity of light and by maintaining the room as dark as possible. Thermal injury to the skin can be minimized by reducing the contact of light to the skin between 15–30 seconds. The halo of light around the probe is visualized, measured and compared on two sides.

It is a useful device for point-of-care prompt diagnosis of air-leaks (pneumothorax, pneumomediastinum and pneumopericardium), hydrothorax and chylothorax. Cranial transillumination is useful for the diagnosis of subdural hematoma or effusion, hydrocephalus, hydranencephaly, cystic hygroma and



craniocervical meningocele. Transillumination of abdomen and pelvis can be used for diagnosis of hypertrophic pyloric stenosis, necrotizing enterocolitis, hydronephrosis, inguinal hernia and hydrocele. It can be used for delineation of bladder for suprapubic aspiration of urine. Transillumination is a useful aid for venous and arterial cannulation in neonates.

### Phototherapy Unit

Phototherapy is now generally accepted as a safe and effective method for treatment of neonatal hyperbilirubinemia. A light source designed to give an irradiance or flux of  $10\text{--}30\ \mu\text{W}/\text{cm}^2/\text{nm}$  between  $400\text{--}520\ \text{nm}$  wavelength range at the mattress is ideal. Blue light is more effective than the white light but former interferes with the observation of the infant. Special blue lamps with a peak output at  $425\text{ to }475\ \text{nm}$  are most efficient for phototherapy and these do not emit harmful ultraviolet rays. To enhance irradiance or flux, four blue compact fluorescent tubes (F 20 T12/BB and Philips TL 20 W/52) and two white fluorescent tubes can be used because excessive blue color makes evaluation of the baby difficult and is uncomfortable to the eyes (Figure 1.14). It is preferable to use 40 W 2 feet long tubes which are economical with reduced recurring expenses. These units provide irradiance of  $20\text{--}30\ \mu\text{W}/\text{cm}^2/\text{nm}$  in the  $400\text{--}520\ \text{nm}$  range. Cooling fan is required to reduce radiant heat exposure to the baby. The nude infant may be exposed under a portable or fixed light source kept at a distance of about 18 inches (45 cm) from the skin. Double-light system, where total baby is exposed from below and above, has been used for more effective light exposure. The conventional double surface phototherapy is uncomfortable and unfriendly to the baby who is made to lie on a cold and hard perspex sheet. Instead, intensive single surface phototherapy can be given by using tubes providing



Figure 1.14 A compact fluorescent light phototherapy unit.

greater irradiance (40 W, 2 ft, TL-52) and by reducing the distance between the tubes and the baby to  $15\text{--}20\ \text{cm}$ . The tube light should be covered with plexiglass or plastic sheet to screen out ultraviolet rays. The flux density reduces with time and average rated life of tubes vary between 1000 to 2000 hours. The tubes should be replaced when their ends become black or spectral radiant energy ('flux') at the level of skin is less than  $8\ \mu\text{W}/\text{cm}^2/\text{nm}$ .

Spotlight phototherapy units are available which are equipped with a 150 watt 21 volt halogen bulb with a specially coated reflector which absorbs harmful infrared waves. The latest phototherapy units are based on the principle of fiberoptics in which an illuminated blanket is wrapped around the baby. It ensures exposure of greater surface area and is ideal for providing double-surface light exposure. The baby is placed on the fiberoptic biliblanket or light-emitting diode (LED) mattress and additional phototherapy is provided with blue compact fluorescent tubes from the top. The effect of phototherapy unit can be enhanced by using slings or curtains made of white cloth or aluminium to reflect light on the baby. Newer phototherapy units are equipped with dosimeter to calculate cumulative exposure to phototherapy. Recently, gallium nitride light-emitting diode units have been launched to provide intense phototherapy benefits. They produce minimal heat and provide narrow luminous spectra in the blue-green range of visible spectrum of light with massive delivery of irradiance upto  $200\ \mu\text{W}/\text{cm}^2/\text{nm}$ .

The efficacy of phototherapy unit is not dependent upon the intensity of light but on the irradiance or flux. Most phototherapy units in the country are suboptimal because their flux is not monitored. In a large NICU, in-house fluxmeter should be available or the supplier should be asked to periodically check the flux and replace the tubes when irradiance drops below  $8\ \mu\text{W}/\text{cm}^2/\text{nm}$ . The phototherapy unit is put on for at least 10 minutes. The irradiance is measured by placing the sensor probe of the fluxmeter at a distance of 50 cm. The total irradiance read-out given by the fluxmeter is averaged to  $\mu\text{W}/\text{cm}^2/\text{nm}$  by dividing it by the bandwidth, i.e. for the instrument providing waveband range  $425\text{--}475\ \text{nm}$ , it is divided by 50. It is recommended to use a spectroradiometer (calibrated for  $430\text{--}490\ \text{nm}$  waveband) to measure the irradiance (Figure 1.15).

### Heart Rate Monitor

Among various electronic gadgets for monitoring vital signs, cardiac monitor showing digital display of heart rate (along with audible beep) or an electrocardiographic configuration on an oscilloscope or both, is most



Figure 1.15 Irradiance meter.

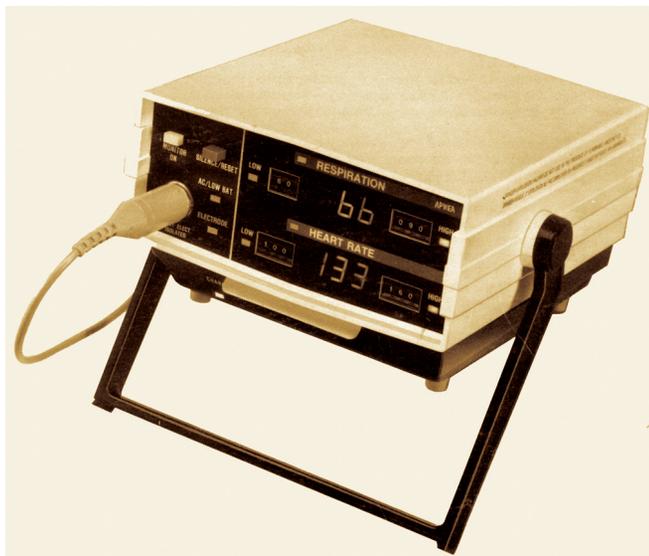


Figure 1.16 Heart rate and respiration monitor.

useful. Generally, an apneic attack is followed by bradycardia within 20 seconds so that heart rate monitor (with an alarm set at heart rate of less than 80 per minute) can be used with advantage over an apnea monitor. They are ideal to monitor high-risk infants and are especially useful during prolonged procedures, such as exchange blood transfusion and surgery (Figure 1.16).

### Respiratory Rate and Apnea Monitor

The respiratory monitor based on impedance technique measures changes in the electrical resistance during breathing. The electrode is fixed on the chest wall to pick-up signals which are digitally displayed as

respiratory rate. The respiratory excursions can also be displayed on the oscilloscope. The conventional apnea monitors are based on air mattress having plethysmographic sensor. The mattress is placed underneath the chest of the infant and mechanical alterations produced by the respiratory movements of the infant are recorded and displayed. When infant stops breathing, after a variable interval of 10 to 20 seconds depending upon the preset lag, the instrument emits a beep and displays red light warning signal.

A pulse oximeter in which an alarm gets activated when a baby develops bradycardia (heart rate < 100/min) or desaturation ( $SpO_2 < 90\%$ ) is a useful and reliable alternative to an apnea monitor.

### Blood Pressure Monitor

Recording of blood pressure by flush or conventional method is inaccurate and time consuming in newborn babies. Direct arterial pressure can be recorded by introducing a transducer into umbilical artery but this method is invasive and fraught with complications and should be reserved for critically sick VLBW babies on assisted ventilation. Doppler system based on the principle of ultrasound waves provides an accurate and non-invasive means for recording blood pressure in newborn babies. The ultrasonic waves are picked up by the transducer located in the cuff. The usual cuff size to cover two-thirds of the upper arm of a neonate varies between 2.5–4.0 cm depending upon the birth weight. The blood pressure reading may be unreliable, if baby is crying or moving. The blood pressure instruments based on oscillometric technique are more accurate and should preferably be used. They are more reliable and are not affected by the movements of the baby. The instrument provides continuous digital display of heart rate, systolic, diastolic and mean blood pressure. The mean blood pressure is based upon diastolic pressure plus one-third of the pulse pressure (systolic – diastolic pressure). Blood pressure varies depending upon the gestational age of the neonate. Means arterial blood pressure correspond to gestational age in weeks. In general, diastolic pressure lower than 25 mm Hg and mean blood pressure of less than 30 mm Hg is a cause for concern. A diastolic blood pressure of >50 mm Hg in a preterm and >60 mm Hg in a term baby is suggestive of hypertension. A pulse pressure of >20 mm Hg is suggestive of opening up of ductus arteriosus. There is a provision for alarm or warning signal when blood pressure falls or rises beyond certain preset limits (Figure 1.17). In future, finger plethysmography with the help of a small cuff and a light source may provide a constant display of mean blood pressure, heart rate and arterial oxygen saturation.



Figure 1.17 Noninvasive blood pressure monitor.

### Multichannel Vital Sign Monitor

The multiple channel complex monitors are available to display and record all the vital signs on an oscilloscope. They are very useful but extremely expensive. They are equipped to record temperature at different sites, heart rate, respiratory rate with apnea alarm, invasive and noninvasive blood pressure and pulse oximetry. ECG, pulse waves and respiratogram are displayed on the oscilloscope. There is a need to have a computer based monitor to analyze all the information provided by complex vital sign monitors (Figure 1.18).

### Infusion Pump

In view of the fact that relatively small quantities of fluids need to be infused and minor errors in rate of administration may prove lethal to low birth weight babies, constant infusion pumps with accurate control are essential to meet these requirements. In centers



Figure 1.18 Multichannel vital sign monitor.



Figure 1.19 Syringe-based infusion pump. The flow rate of drip can be regulated between 1.0 and 99.9 mL/hour with this device.

where parenteral nutrition is used for the care of sick babies, the use of infusion pumps has become obligatory. The infusion pump is a sophisticated electronic micropump which displaces fluid and a microprocessor or pressure transducer controls the rate of fluid delivery. Various devices used for accurate administration of fluids in neonates include gravity-dependent drip rate regulators, volumetric infusion pump and syring pumps accepting a wide range of syringes. The rate of infusion is either depicted as drops/minute (1–99 drops/minute) or in terms of volume (1.0–99.9 mL/hour) through a disposable cassette or plastic syringe. The syringe-based infusion pumps are ideal for administration of drugs or intralipid. It is desirable to buy an infusion pump which accepts syringes of different sizes (20, 50, 100 mL) and of all makes and should work both on mains and Ni-Cd batteries. The syringe and tubing must be changed every 24 hours to reduce the risk of nosocomial infection. The latest infusion pumps have inbuilt alarms to signal occlusion of flow, air in the system, system failure and low battery charge (Figure 1.19). The infusion site must be watched diligently for any extravasation because infusion will not stop due to the effect of pumping force. The new generation “smart” infusion pumps are available which are equipped with computerized prescriber order entry (CPOE) and automatic or programmed medication system to reduce the risk of adverse drug events.

### Microcentrifuge

Centrifugation is done to separate solid particles or cells suspended in a liquid medium, like blood, urine and various body secretions, (CSF, gastric aspirate) and serosal transudates and exudates. Laboratory microcentrifuge is used for measuring hematocrit or packed cell volume (PCV) and for separation of plasma from cellular elements of blood for estimation of bilirubin in a microcapillary sample (50–70  $\mu$ L). The main



**Figure 1.20** Laboratory microcentrifuge.

components of the centrifuge include a rotor with slots for placing capillaries, a lid with a lock, a timer and a knob for adjusting the speed. The microcapillaries made of borosilicate glass and certified for centrifugation at a high speed of 10,000–15,000 rpm are recommended for use. Heparinized microcapillaries with internal diameter of 1.0 mm and length of 7.0 cm are used. After taking the blood sample in the tube, one end is sealed with plasticine. The placement of tube/s in the slots should be balanced on two sides by placing blood or water-filled capillary tubes on the identical or corresponding slots on the opposite side of the rotor. The instrument should be kept at least 30 cm away from the wall for proper dissipation of heat. The motor is provided with a blower to ensure that the temperature of the machine is not allowed to cross 40°C. After placing the capillary tubes in slots (including balancing capillaries), the centrifuge is turned on and set to rotate at 10,000 rpm for 5 minutes (Figure 1.20). The instrument should be kept clean and any blood spills should be wiped off with a wet gauze piece or 10% bleach solution. The instrument should be kept lubricated and its motor brush should be checked every 3 months.

### Bilirubin Analyzer

The spectrometric bilirubinometer works on the principle of two wavelength direct spectrometry with the help of a light source that emits a narrow beam of light at 465 nm and 540 nm. The light beam passes through a slit in the microcapillary tube holder or a cuvette and the unabsorbed light is detected by a photodetector. The microcapillary tube containing 50–70  $\mu\text{L}$  of baby's blood is blocked on one end with plasticine and centrifuged at 12,000 rpm for 5 minutes



**Figure 1.21** Twin beam bilirubin analyzer.

to separate out the plasma or serum. The serum or plasma column should cover the entire length of the slit through which the light waves pass. The capillary slit must be kept clean of any dust or particles of plasticine to ensure accuracy of results. The instrument provides direct read-out of total serum bilirubin which is reliable for taking therapeutic decisions for the management of neonatal hyperbilirubinemia. The hematocrit can be read off from the same sample and serum can be subsequently used for determination of C-reactive protein or other biochemical tests; thus minimizing the need for blood sampling (Figure 1.21).

Apart from bilirubin, there are several other components in the plasma, like oxyhemoglobin, transferrin, methemalbumin and lipids which can interfere with absorption of light. The instrument is so calibrated by using complex mathematical equations and correction factors, that the bilirubinometer gives a reliable estimate of total bilirubin. Nevertheless, beta-carotene levels of blood can interfere with test results but fortunately carotenoids are not present in the serum of newborn babies. However, after an exchange blood transfusion with adult blood, transfused carotene may provide falsely high values of bilirubin. Hemolysis does not interfere with the reliability of spectrometry method of bilirubin estimation unlike conventional Diazo method.

### Transcutaneous Bilirubinometer

The yellow discoloration of skin and subcutaneous tissues can be quantitated and equated to total bilirubin value with the help of a photoprobe. The probe is pressed against, forehead or upper end of sternum. When instrument's xenon lamp flashes green, press the trigger to take the reading. Five readings should be taken and instrument displays the mean value. The light passes through inbuilt fiberoptics and reflectometer and is analyzed by computerized spectrophotometer to



provide immediate digital display of total bilirubin. It is a useful bedside screening method for the young resident doctor to assess the degree of jaundice. There is a good correlation between transcutaneous and biochemically assessed bilirubin values. It gives an estimate of only total bilirubin which, however, is quite satisfactory because there is hardly any elevation of direct-reacting bilirubin during first week of life. Skin pigmentation of black babies may interfere with transcutaneous bilirubin evaluation. In such cases, photoprobe placed against a drop of blood taken on a filter paper, has given reliable estimate of serum bilirubin. The latest multi-wavelength reflectance meter (BiliChek by Norcross) or dual wavelength reflectance meter (JM-103 by Minolta/ Air shields) provides reliable estimate of total serum bilirubin without any interference by skin pigmentation or gestational age of the baby. According to the guidelines of American Academy of Pediatrics, transcutaneous bilirubinometry (TcB) can be used as a surrogate of serum total bilirubin (STB) for screening of jaundice in term and near-term neonates. However, bilirubin level must be confirmed by a spectrometric bilirubin analyzer or Diazo method before starting any therapeutic intervention. During phototherapy, a small area of skin should be kept covered to serve as a reference point to reliably monitor transcutaneous bilirubin levels. Icterometer is a plastic strip depicting different shades of yellow color and can also be used to match the yellowness of the skin of the baby to roughly assess the severity of jaundice.

### Transcutaneous Blood Gas Monitor

Sick preterm infants with respiratory difficulties require frequent arterial blood sampling for blood gases and acid-base analyses. Arterial electrode placed in umbilical artery has been successfully used for continuous monitoring of PaO<sub>2</sub> but it is complicated by inherent hazards of umbilical vessel catheterization with indwelling catheter. The availability of non-invasive transcutaneous monitor is indeed a useful technological advance in the field of bioengineering during the last decade. This has simplified constant monitoring of oxygen tension *in-vivo* with the hope that sequelae of hypoxia and hyperoxia in the newborn can be reduced. It utilizes a miniature Clarks' electrode which can be heated to 44°C. The sensor is slipped over the membrane assembly and is affixed over the chest or upper abdomen. The heated skin electrode produces local hyperthermia causing vasodilation, thus arterializing the capillary bed under the electrode. Molecular oxygen diffuses from the dilated capillaries towards the cathode (platinum) of the electrode where

it is reduced. The resultant current generated by the flow of electrode is proportional to the partial pressure of oxygen which is continuously displayed on the digital read out. The transcutaneous PO<sub>2</sub> values are quite reliable and comparable to simultaneous PaO<sub>2</sub> which should be cross-checked every 4 to 6 hours. Due to risk of skin burns, the site of sensor should be changed every 2 hourly. When the electrode becomes loose, room air may leak under the sensor to produce spuriously high TcPO<sub>2</sub> values (usually above 150 torr). Transcutaneous oxygen monitoring is essential for optimal management of infants with respiratory distress syndrome and frequent apneic attacks. It provides diagnostic information in several clinical situations. In infants with cyanotic congenital heart disease, TcPO<sub>2</sub> cannot be raised above 100 torr by administration of 100% oxygen. The right-to-left shunting at the ductal level can be suspected by using two skin sensors, one placed over the right upper chest (pre-ductal) and the other placed over left lower abdomen (post-ductal). A discrepancy of greater than 20% in TcPO<sub>2</sub> value obtained by two skin sensors is indicative of significant right-to-left shunt. Lastly, if TcPO<sub>2</sub> value is considerably lower than simultaneous PaO<sub>2</sub> level, it is suggestive of peripheral vasoconstriction or impending shock. Transcutaneous oxygen monitors have lost the initial enthusiasm because they are time-consuming and cumbersome to use.

Transcutaneous carbon dioxide monitors are also available though they are very expensive. The TcPCO<sub>2</sub> sensor is larger in size and work on the principle of Stowe and Severinghaus. Like the oxygen sensor, CO<sub>2</sub> sensor also needs to be kept heated at 44°C and its site is changed every 3 to 4 hours. Technology is also available for continuous monitoring of tissue pCO<sub>2</sub> with a mass spectrometer and infrared method. The continuous monitoring of tissue pH is also feasible but it is rather invasive and requires insertion of an indwelling electrode either over the surface of a muscle or in the subcutaneous tissue.

### Pulse Oximeter

Pulse oximeter provides a simple, convenient and non-invasive method for continuous monitoring of hemoglobin saturated with oxygen. It has virtually replaced the transcutaneous monitors. The arterial blood oxygen saturation (SpO<sub>2</sub> or SaO<sub>2</sub>) can be determined transcutaneously with an accuracy of ± 2% by measuring the absorption of two selected wavelengths of light. The light generated in the sensor (probe) passes through the blood and tissues and is converted into electronic



**Figure 1.22** Pulse oximeter for monitoring arterial oxygen saturation and heart rate.

signals by a photodetector located in the sensor. The oxyhemoglobin and reduced hemoglobin allow different amounts of light at selected wavelengths to reach the photodetector. The monitor gives the digital display of arterial oxygen saturation, pulse rate and audible pulse tone (Figure 1.22). Most instruments have a facility to set alarm limits for  $\text{SaO}_2$  (low and high) and for pulse rate which can provide a dual function of an apnea alarm. A hand-held pulse oximeter which runs on batteries can be used during transport of sick babies. The flex probe (sensor) can be affixed on the fingers, toes, hand and dorsum of the foot of the baby. The sensor containing the photocell is extremely sensitive to light and must be shielded from strong external light sources, like observation light and phototherapy. Do not apply cuff of blood pressure monitor on the same limb where sensor is affixed. The probe site should be periodically changed to prevent damage to skin. Pulse oximetry provides a simple, convenient and non-invasive method for continuous monitoring and display of  $\text{SaO}_2$ . It is ideal for early detection of hypoxia in critically sick newborn babies but it has its own limitations to identify hyperoxia because oxygen dissociation curve is displaced to the left in newborn babies. To safeguard against the risk of hyperoxia and retinopathy of prematurity, it is recommended that the upper limit of alarm for oxygen saturation should be set at 95%. Arterial oxygen saturation should be maintained between 90 and 95% for acute conditions and 85 and 90% for extremely preterm babies and chronic situations. Pulse oximetry is unreliable when there is poor perfusion due to shock and hypothermia, excessive movements of limb, exposure of probe to light sources, severe anemia, dyshemoglobinemias (carboxyhemoglobin and methemoglobin), and when blood pressure cuff or splint is applied proximal to the site of probe. Fetal hemoglobin and bilirubin do not affect the accuracy of pulse oximeter.

### Capnography or End Tidal $\text{CO}_2$ ( $\text{EtCO}_2$ ) Monitor

This is a simple, noninvasive and quick method to assess alveolar  $\text{CO}_2$ . Apart from water vapor,  $\text{CO}_2$  is the only component of alveolar gases which absorbs infrared rays. When water vapor is eliminated, infrared analyzer provides a good measure of  $\text{CO}_2$  concentration. Carbon dioxide, an end product of cellular metabolism, is transported from the cells via circulation, diffuses into the alveoli and exhaled through the airways. Thus  $\text{EtCO}_2$  values reflect metabolism, pulmonary perfusion, alveolar diffusion and ventilatory efficacy. In normal subjects,  $\text{EtCO}_2$  is an accurate approximation of "average" mixed alveolar gas composition. In spontaneously breathing infant, nasal cannula is used for air sampling while in a baby on assisted ventilation, an adaptor is placed between endotracheal tube and the ventilator circuit. It is preferable to buy the mainstream analyzer (instead of sidestream analyzer) because couvette can be mounted directly in line with the endotracheal tube without any risk of blockage.

The  $\text{EtCO}_2$  range varies between 0 and 99 mmHg with an accuracy of  $\pm 2$  mmHg for values between 0 and 40 mmHg and  $\pm 5$  mmHg for values between 41 and 99 mmHg. It is a useful modality to assess whether endotracheal tube has gone into the esophagus or it is kinked/blocked giving  $\text{EtCO}_2$  value of near zero. The gradient between arterial carbon dioxide and  $\text{EtCO}_2$  ( $\text{PaCO}_2 - \text{EtCO}_2$ ) should be calculated. In infants with normal lungs, the gradient is usually upto 5 mm Hg. In neonates with V/Q abnormalities, the gradient may be 10–20 mmHg. Even when there is a wide gradient,  $\text{EtCO}_2$  is a reliable predictor of  $\text{PaCO}_2$  because gradient is usually constant over a long period of time. A sudden increase in the gradient is indicative of an increase in the dead space with a decrease in pulmonary perfusion. When the gradient between  $\text{PaCO}_2$  and  $\text{EtCO}_2$  drops to less than 10 mmHg, it is indicative of improved lung function and feasibility of weaning. However, due to various limitations and availability of more reliable monitoring modalities, capnography is rarely used in newborn babies.

### CPAP Delivery System

Continuous positive airway pressure (CPAP) is a useful and affordable technology to manage neonates with RDS and respiratory insufficiency. In contrast to assisted ventilation, it conserves surfactant, improves functional residual capacity (FRC) and reduces the risk of bronchopulmonary dysplasia. Infant on CPAP can be fed with an orogastric tube. The feeding tube is kept plugged for 20 to 30 minutes after the feed to prevent