Challenges posed by infant incubators and their potential mitigation

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Introduction

Babies born before 37 gestational weeks are labelled preterm births. As per World Health Organisation (WHO) 2019 data, around 1 million preterm babies die annually due to unavailability of mother’s womb like environment in extra-uterine life. Categories of gestational age are shown in Table 1.

Table 1: Categories of gestational age

<table>
<thead>
<tr>
<th>Gestational age (weeks)</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>32-37</td>
<td>Late preterm</td>
</tr>
<tr>
<td>28-32</td>
<td>Very preterm</td>
</tr>
<tr>
<td>Less than 28</td>
<td>Extremely preterm</td>
</tr>
</tbody>
</table>

Reasons for infant mortality are very low birth weight (<1000g), insufficient gestational age for infant to develop the mechanisms required to cope with the environment outside the mother’s womb and heat loss though radiation, conduction, convection and evaporation. Prematurely born babies (Preemies) are unable to conserve heat or change their posture to avoid thermal stress and cannot be kept in an open crib but should be provided an appropriate microenvironment which should be like an artificial mother’s womb.

An infant incubator is a device where the infant will be kept and is a device with facilities to control various parameters of its microenvironment for the infant’s comfort and benefit. It can take special care of the incubant infant by controlling temperature, relative humidity, weight gain, baby movements and oxygen concentration inside it. Some advanced neonatal incubators can also control the intensity of incident light, sound, stop unwanted smells and reduce the chances of the preemie getting infections.

Infant Incubator

It has the following features:

- **Temperature control mode:** This maintains the baby’s body temperature and the incubator air temperature within the WHO recommended range and enables us to control the temperature both manually and automatically. Failure to do this could cause hypothermia leading to insensible water loss from the skin of the preemie.

- **Relative humidity (RH) control mode:** This keeps the RH inside the incubator with an adjusting facility from lowest to highest percentage limit. It maintains the desired percentage of humidity converting the water into vapour. Incubator needs a water storage tank for this purpose.

- **Oxygen control mode:** This maintains the oxygen concentration inside the incubator at a specified level essential for the baby’s wellbeing. Above three features of the incubator are servo controlled and are continuously measured and checked with the specified values to find if there is any error and regulates them immediately to obtain zero error.

- **Weighing mode:** Only sophisticated incubators have this feature. It measures the weight of the baby all the time ranging from 0 to 6 kg. Resolution of this feature is
important for preemies with low birth weight.

- **Optional integrated monitoring of vital functions**: This is the difference between an infant incubator and the neonatal intensive care unit (NICU). Infant incubator provides the required environment for the baby, but NICU can also measure the baby’s vital functions like oxygen saturation, pulse rate, perfusion index, pleth variability index and non-invasive continuous haemoglobin.

- **Connectivity**: This enables the infant incubator to communicate the status of the baby with the concerned doctor and parents. Some infant incubators can also send a live feed inside an infant incubator direct to the mobile phone of the concerned parties with the help of a webcam.

Some international and Indian infant incubator manufacturing companies and their popular products are shown in Table 2.

<table>
<thead>
<tr>
<th>Name of company</th>
<th>Temperature</th>
<th>Relative humidity</th>
<th>Oxygen</th>
<th>Weighing scale</th>
<th>Vitals</th>
<th>Connectivity</th>
<th>International/Indian</th>
<th>Popular product</th>
</tr>
</thead>
<tbody>
<tr>
<td>G.E. Healthcare</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>International</td>
<td>Giraffe incubator</td>
</tr>
<tr>
<td>Atom Medical Corp.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>International</td>
<td>Atom-Model-101</td>
</tr>
<tr>
<td>Bistris Co. Ltd.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>International</td>
<td>BT-500 infant incubator</td>
</tr>
<tr>
<td>Fanem Ltd.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>International</td>
<td>Vision advanced 2286</td>
</tr>
<tr>
<td>Universe surgical</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Indian</td>
<td>Infant incubator</td>
</tr>
<tr>
<td>Desco Medical India</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Indian</td>
<td>BCB-105&amp;106</td>
</tr>
<tr>
<td>Draeger India Pvt. Ltd.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Indian</td>
<td>Isolette C2000</td>
</tr>
<tr>
<td>Medi Waves Inc India</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Indian</td>
<td>Baby incubator</td>
</tr>
</tbody>
</table>

Table 2: Popular products of international and Indian companies and their feature comparison

It is observed that Indian manufacturers, unlike international manufacturers, aim to provide only features like thermoregulation, RH level control and oxygen level control but not features like vital monitoring and connectivity. This approach must change in order to reduce importation of incubators from high income countries.

**Challenges posed by infant incubators**

**Direct challenges affecting preemies and their mitigation**

- **Inaccurate thermoregulation**: Most infant incubators are not performing thermoregulation effectively as they do not take into account all radioactive, conductive, convective and evaporative exchanges with the surrounding environment. This can be resolved using generalised predictive control (GPC) that takes into account all parameters involved in maintaining the temperature inside an infant incubator.

- **Lack of standardization of relative humidity (RH) levels**: Preemies face conditions like trans-epidermal water loss (TEWL), hyperthermia, electrolyte imbalance, oxygen consumption, infection, skin integrity and will be affected by the amount of RH inside the infant incubator. There is also a practice gap in the nurses handling these incubators due to lack of standardization of RH. The inconsistent use of these levels and gaps in nursing practice have an adverse effect on the preemie. It is also found that non-standard use of high RH even after the first week of life of the preemie will cause broad disparities in RH management in clinical practice. This challenge can be mitigated by the standardization of RH levels and giving practice guidelines to adhere to the incubator handling nurses.

- **Slow and non-homogeneous temperature distribution**: To avoid health risks to the preemie, infant incubator must be able to keep the temperature inside the hood at a homogeneous level and should also be able to maintain the desired temperature as quickly as possible as there will be unavoidable disturbances to the microenvironment inside the infant incubator by parents and health professionals. Unfortunately, existing incubators are unable to do these things and this problem can be mitigated with an infant incubator having a modular thermoelectric heat pump system (MTEHPS).

- **Inefficient thermoregulation**: About 85% of the total electrical power used by existing incubators is consumed by the resistive heating element and they also have temperature fluctuations (± 0.8°C) in the hood; these systems are generally designed to work at room temperature and have only a temperature increasing mechanism; in case it is being transported or shifted to some other place and the temperature is high during transition, they are not equipped to lower the temperature so that the preemie would not get hyperthermia. This problem can be solved with the help of an infant incubator with an improved modular thermoelectric heat pump system.

- **Inability of current infant incubators when
Indirect challenges of infant incubators affecting the preemies and their mitigation

- **Health risk produced by high-level noise in NICU**: NICUs have increased the survival of very low birthweight babies and preemies significantly. However, noise level in the NICU is very high due to obvious reasons of the surroundings of any healthcare facility like alarms, loudspeaker announcements, nurse talk, radiator warmer and other activities. The high levels of noises in the NICU have been shown to cause many negative health problems including sleep disturbance and other forms of stress, as well as changes in physiological responses such as heart and respiratory rate, blood pressure and oxygen saturation. These health risks can be avoided by using wireless-communication integrated hybrid active noise control system (HANCS) in infant incubators to improve the health outcomes and to improve bonding opportunities for infants and parents.

- **Unavailability of low-cost, foldable and portable neonatal incubators**: Conventional neonatal incubators are very expensive and many healthcare institutions in poor countries cannot afford them. This challenge can be met by using low-cost incubators with better performance like Kangaroo Mother Care (KMC), Embrace Warmer (EW) and Handy Incubator (HI). These use Internet of Things Technology, cloud computing and wireless medical sensor networks in designing and developing neonatal incubators, which reduce the total cost of manufacturing infant incubators and has significantly improved remote healthcare monitoring. Very few infant incubators, like neonatal portable foldable emergency incubator and MOM incubators are foldable or inflatable, hence occupying very small space and making them portable and ideal for emergency applications. If these incubators are manufactured locally in low-income countries instead of importing them...
from high-income countries where the labour cost is more, they will become more affordable, user friendly and easy to maintain.  

- **Balance between cost benefit and safety:** Annual medical device maintenance and calibration cost in healthcare institutions is approximately 1% of the total budget. Due to this huge money requirement healthcare institutions tend to use cost-cutting measures which affect the safety and quality of healthcare provided to patients. Only 30% of the ISO 17025 accredited laboratory tested medical devices like mechanical ventilators and infant incubators are working properly and complying with international standards for all measured parameters. This problem could be solved by introducing machine learning algorithms like Decision Tree Algorithm instead of the traditional Medical Device Management Strategies (MDMS), which will increase the safety and quality of healthcare provided by healthcare institutions while getting cost optimization and better resource management.  

- **Unwanted disturbances to the microenvironment of the preemie:** Preemies need a microenvironment that is similar to the mother’s womb and it should not be disturbed unnecessarily or should be disturbed the least number of times possible. It is possible to reduce these disturbances with the help of technologies like Near Field Communication (NFC) interface that allows the identification of doctors, the view of the patient evolution with tablets and the introduction of new data by the doctor. It is also suggested to use contactless methods to measure and monitor the vitals of the infant without disturbing the microenvironment of the incubator with the help of techniques like infrared imaging.  

- **Problems faced by end users:** Nurses and technicians are the predominant users of infant incubators. They use incubators to perform various tasks but predominant usage is for admission of preterm newborns and troubleshooting of the equipment. Even though they face many problems while using incubators, the most significant problems refer to alarms and configuration of the air and skin modes as the interface is not intuitive to users. These challenges can be overcome by making conscious efforts to mitigate errors from the beginning of the product development process to the training of the main users and by using Human Factors Engineering (HFE) instead of Conventional Product Design (CPD).  

- **Internet dependency for networking of incubators:** Infant incubators that are existing in different locations can be connected to a centralized network using wireless technologies like Wi-Fi (802.11n) or Low Power Wide Area Network (LPWAN) protocols in the range of 30 – 100m but with the help of latest technology like Long Range Networks (LoRa) it is possible to send data through a very long distances at very low power. Using LoRa it is possible to connect all infant incubators existing within a radius of a hundred kilometres to a single central network without using internet and transport them from once place to another without losing connection to the central database. Different branches of a healthcare institution can form a centralized network which can register the medical data in a common database without any threat from cyber-attacks of the internet and it would be easy to use the pooled resources and it also gives cost benefit to the healthcare institution.  

Table 4 summarises the merits and demerits of the mitigation methods.

<table>
<thead>
<tr>
<th>Indirect challenge</th>
<th>Mitigation method (MM)</th>
<th>Merits of MM</th>
<th>Demerits of MM</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-level noise in neonatal intensive care unit (NICU)</td>
<td>Wireless-communication integrated hybrid active noise control system (HANCS)</td>
<td>Reduced health risk, less stress &amp; improved relationship between infant &amp; parents/health professionals</td>
<td>Possible auditory deprivation</td>
</tr>
<tr>
<td>Unavailability of low-cost, foldable and portable neonatal incubators</td>
<td>Kangaroo Mother Care (KMC), Embrace Warmer (EW), Handy Incubator (HI), MOM incubator (MOMI)</td>
<td>Low cost, foldable, portable and maternal-preemie bond (MPB)</td>
<td>KMC &amp; EW cannot monitor vitals of preemie, HI costliest, HI and MOMI have no MPB</td>
</tr>
<tr>
<td>Balance between cost benefit and safety</td>
<td>Machine learning algorithms like Decision Tree</td>
<td>Highest accuracy, enhanced safety, improved quality of healthcare, cost optimization &amp; better resource management</td>
<td>Requirement of huge device database and skilled technicians</td>
</tr>
<tr>
<td>Unwanted disturbances to the microenvironment of the preemie</td>
<td>Near field communication (NFC) and infrared thermal imaging</td>
<td>Identification of doctors and relatives of the preemie and easy progress checking</td>
<td>Contributing to electrometric field (EMF)</td>
</tr>
<tr>
<td>Problems faced by end users</td>
<td>Human factors engineering (HFE)</td>
<td>Optimisation of safety and minimization of the risk of error</td>
<td>Limited expertise</td>
</tr>
<tr>
<td>Internet dependency for networking of incubators</td>
<td>Long range networks (LoRa)</td>
<td>Long communication range, very low power consumption, transportation without loss of link</td>
<td>LoRa is proprietary and data rates are very low</td>
</tr>
</tbody>
</table>
Conclusion
The healthcare community must come together to standardize the RH levels used in incubators for the benefit of the babies. More studies and analyses are needed to know the exact impact of the electromagnetic fields. Efforts must be continued to reduce the overall cost of infant incubators so that it could become a homecare product and its interface should be made as end-user-friendly as possible. The benefits of foldable and portable neonatal incubators should not come at the expense of important features like RH level control and vital monitoring.

References


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