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Neonatal Thermoneutrality in a Tropical Climate

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1. Introduction

Sub-Saharan African countries are notably among the nations with high neonatal mortality (NNMR) and morbidity rates (WHO, 2009). A number of issues have been previously raised in the literature in attempt to define some of the factors that contribute to these such as level of illiteracy among mothers and short supply of healthcare workers (Amadi et al., 2007). However, little has been said of the impact of environmental temperature regulation on the wellness and survival of neonates in this region. The sub-Saharan Africa is well-known for its harsh climatic conditions of high sun intensity and ambient temperatures, often in excess of 35°C, coupled with societal condition of abject poverty. Nursing environment of the neonate, especially pre-terms, is a crucial factor for the maintenance of appropriate body temperature for the physiological stability of the newborn. Classical management of neonatal thermoneutrality in this region of Africa has been dominated by procedures that were handed down from industrialised societies; these being fundamentally compliant to the peculiar climatic factors and social advantages of the countries of origin.

In the last decade, there has been concerted effort to scientifically investigate factors that may be subtly contributing to high neonatal mortality and morbidity in this region. These include meteorological, socio-cultural and technological factors that define the macro- and micro-environments immediate to the neonate. This knowledge is fundamental for the tweaking or outright replacement of the present morbidity-high techniques. This chapter will attempt to explore these factors and their consequences, and discuss the present interventions and techniques that are coincidentally yielding improved outcome in some neonatal centres in the region. The ideas expressed in this chapter were drawn from on-the-spot clinical practice experiences in a decade-on collaborative project that has involved up to 21 neonatal referral Centres across the entire geographical region of the West African state of Nigeria (Figure 1). Recent publications show that this region of African is currently far behind the United Nation's Millennium Development Goal (MDG) target on the survival of infants, and neonatal mortality rate is steadily making this worse (Federal Ministry of Health [FMOH], 2011). Neonatal survival might not necessarily improve by the flooding of the region with 'foreign-culture-biased' sophisticated incubator systems that are not so easy to handle by the users despite the high pricing of these that limit their procurement by the poor countries. There is a perceived socio-cultural dimension of the work place attitude that militates against effective practice of neonatal thermoregulation. This needed to be properly addressed perhaps by the use of affordable and manageable appropriate incubation technology that the people can easily identify with.

Ineffective thermoregulation leads to other complications and patients’ poor response to treatment. Neonatal physiological stability enhanced by adequate thermoneutral control and humidification is an essential factor that enables the neonate to respond well to treatment thereby enabling effective management of associated tropical diseases. An adequate and hygienic incubation technique, appropriately designed for the peculiar tropical settings, will minimise neonatal cross-infection and also reduce disease transmission by the often freely roaming insects in and out of the incubators. Adverse climatic conditions and observed procedural inadequacies of incubator application often lead to overheating, compelling attendants to open up the incubator portholes and windows thereby compromising the microenvironment. The present work seeks to extend the incubator application to create procedures that ensures the minimisation of such compromises.



Fig. 1. Map of Nigeria showing all the states where the collaborating tertiary hospitals are located

In this chapter, four different environments that impact on the new-born baby would be examined. This knowledge is important to be able to effectively understand the thermal needs of the new-born during neonatal care, whether inside an incubator or an open cot. These are:

1. The prenatal environment or the mother's womb that provides for the nurturing of the foetus.
2. The micro-environment or the baby's compartment of an incubator or wrapping in an open cot.
3. The macro-environment or the outer room comprising the interior of the nursery building where the incubators and cots are situated for the nursing of the new-born.
4. The regional-environment or the outside surrounding of the nursery building directly being influenced by the regional climate.

2. Prenatal environment

The neonate's body system observes the law of "garbage in garbage out" in terms of what it does with the ambient temperature of its immediate environment. From clinical experience, it is very easy to observe that an extremely low birth weight neonate will quickly assume a body temperature equal to the ambient temperature of its immediate environment. This has been frequently observed at one of our collaborating neonatal centres in the very hot town of Nguru in Nigeria. In an overheated room, baby becomes hyperthermic and in a cold room, baby becomes hypothermic. Both extremes are devastating conditions, capable of claiming the baby's life and must be avoided. This is why the regulation of baby's environment must be done on patient-specific basis involving the exact extra warming or wrapping required to thermally stabilise such baby. Nature has made an adequate environmental provision for the prenatal period. Baby's immediate past housing, the womb, is a separately controlled environment independent of the foetus's body system and providing it with no worries for self-thermoneutral control. It is therefore essential to anticipate the possible fatal environmental shock that awaits a premature new-born as its organs are not yet functionally ready to completely support the baby outside the womb environment.

The body temperature of a healthy adult is physiologically stabilized about 37°C whether in a temperate climate of 1°C or tropical sub-Saharan African climate of 45°C. The adult expectant mother may be physiologically acclimatised to her 'freezing' or 'burning' weather respectively; however, the foetuses in both climates are accustomed to approximately the same thermal environment of the womb. Individual climatic adaptation for the baby only begins at birth. Therefore the design of a supportive environment for a premature baby must integrate the climatic peculiarities such foetus would be graduating into.

3. Neonatal micro-environment

It is an absolute necessity to provide an enabling environment immediately following premature birth. This calls for a sustainable artificial environment to allow the neonate enough time for its organs to fully mature to provide independent support to withstand the tougher climate of the outside world. This practice ameliorates the shock of a sudden change in environmental conditions that can become catastrophic for the premature new-born. What should such artificial environment possess then? A good design of controllable micro-environment for the baby might be achieved by applying constraints that are enriched with the good knowledge of the womb as well as the climatic and social factors of baby's place of birth. Incubator comes to mind in a clinical setting when neonatal microenvironment is mentioned. In a classical and basic sense, neonatal incubation might speak more of the

provision of a controlled warming for the new-born. It is understandable that provision of uncompromised all-day warming is essential for the neonate in a temperate regional climate of average room temperature of less than 10°C, for example. The baby's inability to maintain its own homeostasis meant that the extra 27°C or more required to attain a body temperature of 37°C must be provided and sustained artificially. The definition for this separate microenvironment for the new-born must however begin to modify when the regional climate changes to another of room temperatures in excess of 40°C. Such elevated ambient temperature in poor hygienic settings as the tropical culture would normally encourage fast breeding of disease transmitting insects even around hidden corners of the incubator. Therefore, appropriate incubation technique capable of effective neonatal care must recognise and integrate the climatic characteristics of the culture the neonate is graduating into. Neonatal incubator care, as is presently practiced in the high ambient sub-Saharan Africa is deficient of this fundamental factor. The race to lower neonatal mortality rate in Tropical Africa might hence not necessarily be dependent on increase of drug donations or over flooding the health facilities with sophisticated incubators. The race might however be won by going back to the fundamentals of neonatal thermoneutral care that are compliant to the conditions of the region. This is a natural 'preventive technique' that would lead to the minimisation of disease occurrences. An effective and climate sensitive neonatal care would ensure a healthy start in life for the promising infant.

Classical incubation techniques in this tropical African climate might not have been fully successful because these were designs developed and originally practiced in climates and cultures that were completely different. This creates opportunities for deficient practices that expose the delicate neonates to unhygienic conditions, insects and infections that soon make them morbid and eventually claim their lives. An unstable thermoneutral environment does not provide the thermal stability the neonate's body system requires to effectively respond to treatment. In response to this, an on-going research adopting new practice procedures in collaboration with 15 different neonatal centres across the region was initiated to address various adverse incubation factors. This has so far proffered solutions that coincidentally improved survival rates in the centres (Amadi et al., 2010). The aim of this work was to present the various thoughts, considerations and incubator care approaches that might have improved neonatal defence against exposure to tropical epidemics that could easily claim their lives.

4. Effect of poverty and illiteracy

A well-looked after pregnancy and professionally efficient antenatal care are essential factors that could promise a healthy baby. These factors would characteristically help to avoid the complications of preterm birth. Poverty and illiteracy create a clear distinction in neonatal mortality rate between developed nations such as the United Kingdom and any sub-Saharan African country such as Nigeria. This is evident from literature reports on neonatal and perinatal mortality rates from these regions (FMOH, 2011; Centre for Maternal and Child Enquiry, 2010). Societal abject poverty and high degree of illiteracy are factors that do not allow the expectant mothers to nurture healthy foetuses or seek professional antenatal care when these are available. It is arguable that most mothers would be happy to observe any rules that would guarantee them a healthy baby. Maternal poverty and illiteracy are outside the scope of the present work; however it sounds reasonable to mention that tackling poverty in sub-Saharan Africa as part of an assembly of measures would go a long way in lowering NNMR of the region.

4.1 Incubator availability

The odd effect of poverty shows up again during the management of the premature baby in terms of inadequacy in the supply of equipment for neonatal nursing. There is endemic insufficiency of functional incubators for the teeming population of the neonates requiring incubator care in a typical referral centre among those involved in the present study. The situation in the region was such that it was common to have only one centre where neonatal special care might be obtained in a catchment population of over 5 million, covering over 30,000 km² of land area. Journeys could take as much as 3 hours to reach the centres and often involving very poor access roads. Such a centre would normally have an average of 35 neonates on admission at any time, yet working with no more than two functional incubators and grossly under-staffed with qualified nurses and doctors. Sadly, up to three babies from different mothers were at times crammed into the same incubator in one of those horrible thermoneutral malpractices to be treated in later sections of this chapter. Our strategic plan to lower neonatal losses due to complications of thermal instability had to be carefully designed to discourage such wrong applications. Ibe (1993) indicated a culture of high admission deliveries for very low birth weight babies within the study region. This is compounded by a high number of referral cases of distressed tiny babies, often stretching the facilities beyond capacity as observed in our study centres. This therefore suggests that a hospital with average on-admission of over 30 patients should operate with a minimum of 20 well-maintained functional incubators, up to 3 radiant warmers, up to 10 phototherapy machines, up to 30 units of cot/incubator installable apnoea monitoring systems and enough attending nurses to guarantee a patient-to-nurse ratio of 5 during every shift. The provision of twenty functional incubators in one hospital alone is almost impossible when the poverty factors of these tropical countries come into play. Hence, an extra ordinary approach to this seemingly impossible situation had to be sought for.

4.2 Budget re-equipping of functional incubator

An earlier study in the tropical region of Africa by Ogunlesi et al (2008) indicated that high point-of-admission hypothermia and general thermal instability contribute a great deal to the high NNMR, stressing the need of incubators in adequate number to re-equip the centres. Many centres were discovered to have several units of broken-down, old and obsolete incubators stacked in equipment stores; others littered the walk ways of the hospital complexes, breeding insects and rodents, promoting environmental pollution and unhygienic facility. Many of these were kept back in the neonatal wards and being used as 'cages' for these babies in such unhygienic manner that could enhance infections and disease transmission (Figure 2). The horrific dirty sights that were revealed upon removal of the mattress trays were enough to wonder why any baby survived at all from the cages. Careful inspections would reveal that many of these still had reusable canopies and trolleys. Proposals for the purchase of adequate number of functional incubators during joint-task meetings with hospital managements would not go well. Lack of adequate funding for the hospitals meant that it was nearly impossible for any of them to acquire enough systems at the local prevailing costs of incubators. These were to be supplied to hospitals at costs higher than €20,000 per unit of incubator. This meant, for a Unit requiring up to 20 incubators, a huge budget of over €400,000 for the purchase of incubators alone in a poorly funded hospital with many other departments to run. The local repair of the broken-down incubators was not a feasible option as the spare parts of few of the current models could not be acquired due to poor supply chain. None of the companies that produced these

systems had any assembly plants or technical representatives to provide the needed technical support. Therefore sustainable solution was not envisaged through this approach. To acquire brand new systems, unlike the use of extended price-plan and after sale maintenance in developed countries, the hospitals in these poor nations would be required by the foreign companies to make outright payment of the full cost. High cost of logistics and unfavourable operating environments might have compelled these companies from any extended technical support to a country like Nigeria at the moment. They hence demanded full out right payment for the systems, leaving the country to bear the full liability of the carcasses when they broke down. An inventory carried out in a certain Teaching Hospital in Nigeria during this period revealed the presence of 45 carcasses of different models of dysfunctional baby incubators in their stores whilst they had no functional one to save tens of babies in its new-born Units.



Fig. 2. An incubator carcass showing the inside immediately below mattress tray (removed); system was in use as is when retrieved

At this junction it was clear that the idea of a new approach to this was inevitable. The old carcasses of incubators that littered the hospitals were again considered and fresh investigations revealed the high availability of these across all the 5 collaborating tertiary (university teaching) hospitals at the time. A research was hence initiated to evaluate and design a process that might apply to re-introduce these obsolete systems to active services in a neonatal ward without necessarily taking recourse to original manufacturers or spare parts. This was to consider the maintainability of the resulting system, carefully selecting options that would ensure availability of spare parts and simplifying the technology to make it easy for the local technicians to handle. Typically available carcasses to apply in these hospitals were of all sorts of brands, age and models, the state of some could be best described as 'horrible' (Figure 3). Carcasses were also literally recovered from hospital dump sites where they were abandoned awaiting evacuation. However, these constituted the closest solutions to the problem required to be solved. The wide variability of these carcasses resulted in the constraint requiring that a workable design must be easily adaptable to any 'model' and 'make' of an item of incubator carcass.



Fig. 3. Abandoned incubators for recycling, recovered from (A) rubbish dump (B) workshop (C) neonatal ward in use (D) scrap metal yard

5. Modelling Recycled Incubators

Recycled Incubator Technique (RIT) speaks of the successful application that most Nigerian tertiary hospitals have used to re-equip their Special Care Baby Units (SCBU) using their formally condemned or obsolete incubators. Many of these old systems were abandoned in the stores or used as ordinary cages (cots) in the Special Care Baby Units.

In the recycling technique that was designed in this study, the casings of the obsolete system were re-used but the functional assemblies of the power unit were completely re-engineered with customized generic digital components. RIT incubators currently make up 80% to 100% of the functional incubators in many Nigerian tertiary hospitals at the time of this report. These included University of Benin Teaching Hospital (UBTH) Benin-City, Lagos University Teaching Hospital (LUTH) Lagos, Jos University Teaching Hospital (JUTH) Jos, Ebonyi State University Teaching Hospital (EBSUTH) Abakaliki, Aminu Kano Teaching Hospital (AKTH) Kano, Federal Medical Centres (FMCs) at Nguru, Gombe, Owerri, EbuteMetta and Abeokuta. Others were University of Nigeria Teaching Hospital (UNTH) Enugu, University of Calabar Teaching Hospital (UCTH) Calabar, University of Ilorin Teaching Hospital (UIH) Ilorin and University of Abuja Teaching Hospital (UATH) Gwagwalada. An RIT system comparatively saves up to 75% of the cost of procuring and maintaining a modern state-of-the-art incubator whilst being functionally akin to these (Amadi et al, 2007). RIT has presently made it possible for some

of these hospitals to currently maintain up to 25 functional incubators whereas they could not simultaneously own up to 3 or none at all in the recent past. This has therefore been described by a Nigerian healthcare organisation as a significant contribution to national development in the Nigerian healthcare system (Committee of Chief Executives of Federal Tertiary Health Institution [CCEFTHI], 2007).

5.1 Original concept

The initial hypothesis proposed that the application of generic assemblies in the rebuilding of the functional mechanisms and electronics of an incubator would drastically reduce the unit cost of incubation in low income countries. To verify and implement this, modern manufacturing techniques based on standard generic assemblies was exploited in a careful design of interfaces for the linking of the generic assemblies. Using the internet market, individual mechanical, electrical and electronic assemblies that could apply to design the functional mechanism of an incubator were cost-competitively selected. These were assembled by design to yield desired outputs necessary for effective maintenance of the unique standard conditions required in an incubator's micro-environment.

5.2 Casing and trolley

System functionality was the primary focus of the RIT, however the overall peripheral finishing must be appealing necessitating a careful investigation of the abilities of self-employed local artisans. It was discovered that individual fabricators, welders and car painters around major cities in Nigeria were good enough in their arts such that with very close supervision these could do excellent jobs. Therefore the best of these artisans were identified and separately guided to renovate the old incubator casings and to finish these with the best possible standards.

5.3 Canopy and plastic components

There were identified artisans that worked on Perspex materials in the small and big cities. Some of these demonstrated good skills in the methods they used in their jobs. Various plastic components of different models of incubator amongst the carcasses were re-designed to be produced as spares for the replacement of the originals; the new designs being such as would be easy to fit into the crafting techniques of the local artisans. Most of the new designs therefore resulted in different shapes from those of the original incubator manufacturers. The changes in the RIT designs for these plastics/Perspex parts were necessary in order to simplify their production as required to ensure good finishing by a closely supervised artisan. The incubator hoods were assessed. Old age and handling could make some of these to become opaque after technical cleaning and must not be reused if not completely clear and transparent. Effort was hence made to reproduce the discarded hoods with locally available Perspex materials by applying simple procedures of working and reshaping of the materials.

5.4 Power unit modules

This is a detachable unit that houses the operational control elements in most incubator designs. A repairer intending to fix a broken-down incubator would normally detach and take this unit away in attempt to diagnose the source of a wrong system signal.

Unfortunately, many of these that were taken away from some of the hospitals by prospective repairers were returned without success as the spare parts were no longer available. Some repairers lost or did not even bother to return the removed power-units after their unsuccessful attempts. In RIT, the casing of the power module was normally reused. However, when these could not be traced to where they were sent to or by whoever removed them, a new simplified casing was designed and locally produced. In some cases, the high aesthetic finishing of the incubator was not altered by this major reconstruction. The Airshields model C100 systems at the Ebonyi State University Teaching Hospital (EBSUTH) Abakaliki and one of the C200 models at University of Benin Teaching Hospital (UBTH) were examples of incubators that were recycled with re-engineered power module casings (Figure 4).



Fig. 4. Recycled incubators, originally carcasses of (A) Airshields model C200 (B) ISIS Mediprema system

5.5 Operating system

Designing and developing a new assembly of an operating system to power the incubator was the most challenging step in the RIT procedure. The chain of electronic and digital communications that powered the intelligence system was generally achieved by interconnectivity of distinct units of circuitry. These were called assemblies and were generic constructs by different companies but selected and arranged by design in RIT systems (Figure 5). All used circuitry could be sourced for internationally through the internet. Specifications of input requirements and expected outputs of such units of assemblies enabled effective integration of these to achieve the ultimate incubator output during the design stage. Ability to design a functional system with this method required a good understanding of how the incubator worked and the different functions of the assemblies that powered it. A good knowledge of human anatomy and neonatal physiology were essentially applied to relate to the outputs of these assemblies to ensure the clinical suitability of the resulting system. These different assemblies or components were then purchased from their individual companies or marketers, appropriately reconfigured to design specifications and mounted in the power module casing. The various outputs, signals and actuations specified in the design were compatible with the applied transduction elements in the incubator; else design adjustments or matching transducers were sought for and applied.

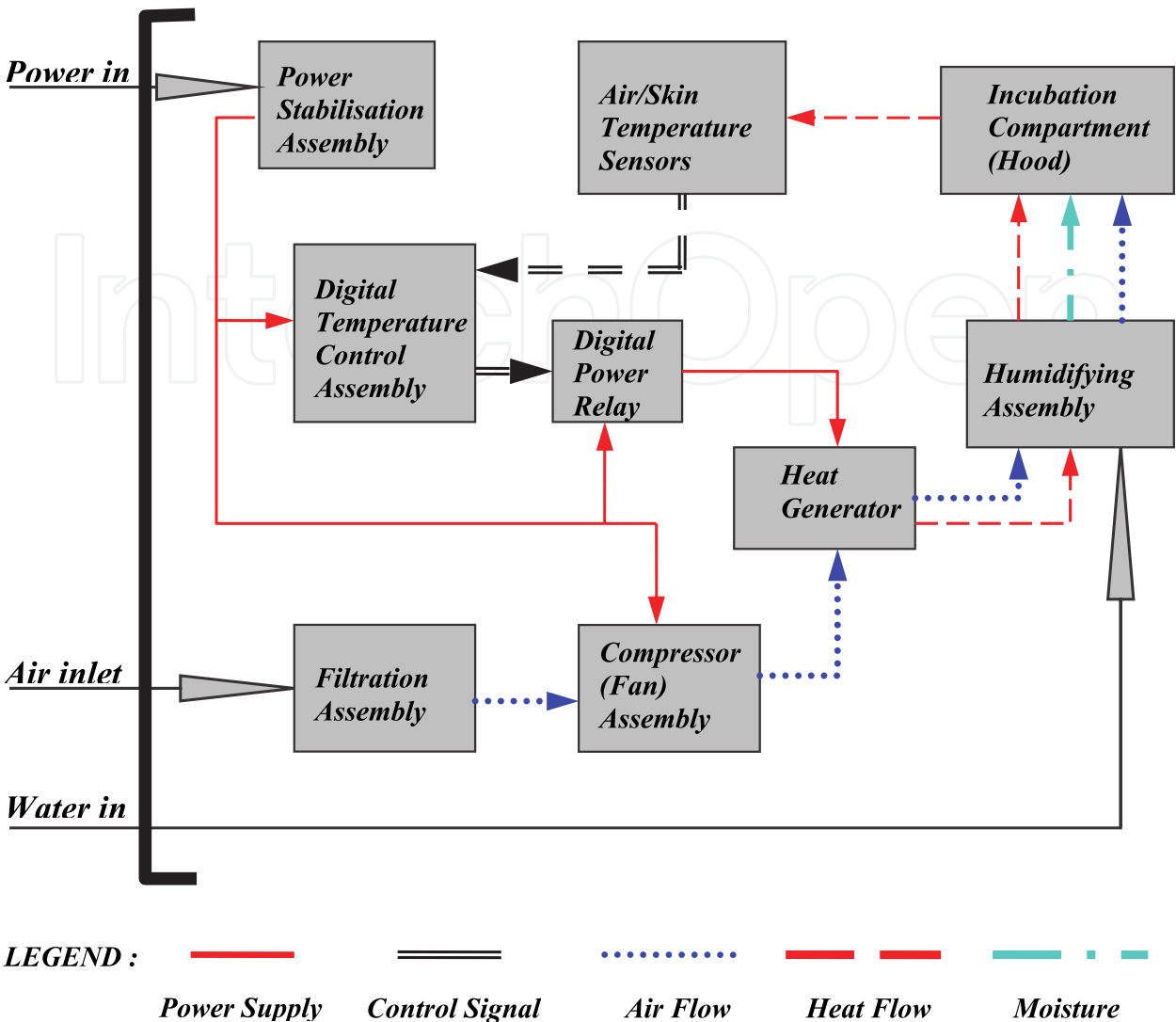


Fig. 5. RIT Assembly Block Diagram (Amadi et al, 2007)

6. Recycling own old incubators

The successful clinical trials of the initial RIT systems paved the way to the present in-depth study on neonatal thermoneutral control in this African tropical climate. The cost of producing an RIT system from a hospital’s fleet of carcasses was demonstrated to be less than 20% of the cost of purchasing one state-of-the-art (STA) incubator (Amadi et al., 2007). This made the idea of incubator re-equipping of the SCBUs an attractive project to administrators of many of the tertiary hospitals that participated in the study. More hospital centres were later attracted to participate in Nigeria when the government approved the supply of STA Draeger Caleo system at a unit cost equivalent to the cost of recycling 7.5 old incubators. It was important to strategically tackle the provision of adequate number of functional micro-environments (housing) for the teaming population of the neonates within the limits of the available funding. It was well-understood that the STA systems have got the excellent finishing of modern technology and sophistication, however, it was necessary to consider the number of babies the same amount of money could house per unit time. RIT approach was hence the easy way of populating the SCBUs with many functional incubators

using the available meagre funding. This would hence create the platform to properly study thermoneutral application in a tropical busy centre. In order to keep the project focused and on course, some of the collaborating hospitals Managements were advised to adopt a 'slow but steady batch-by-batch' recycling approach. This approach allowed a hospital to put a time frame vision for the completion of the recycling of all available carcasses of incubators. The Lagos University Teaching Hospital, for example, had no functional incubators at the start of the project. Ten incubators were initially recycled; there after the Hospital Management recycled 5 more each year to achieve a fleet of 25 functional incubators in three years. This boosted patient flow and staff enthusiasm for work thereby enabling better investigations of the objects of this study in the Centre (Amadi et al., 2010).

The good dedication of most of the collaborators soon led to the successful recycling of all available old incubators in most of the participating hospitals. However, the drive to provide adequate number for the SCBUs meant that some of the hospitals had to take another step of procuring more incubators from the market. The confidence already reposed on RIT made it possible for the Hospitals Managements to use available funds to purchase affordable systems they could easily re-power with RIT component when these failed. This hence secured a sustainable fleet of functional incubators required for the study in each of the participating Centres. The Centres were also encouraged and assisted to add one or more transport incubators in the fleet. This helped to reduce the distress some of the neonates suffered during intra-hospital transports using inappropriate and crude techniques.

6.1 Incubator routine maintenance and functionality auditing

The high neonatal admission delivery in these hospitals coupled with high influx of referrals resulted in extensive demands on the incubators. Many of these functioned continuously for weeks and months without break except when they were to be cleaned for another waiting baby. There was then need to initiate another supportive programme to guarantee sustainability of the functional status of the incubators and freedom from frequent unexpected system failures. This was ensured by the introduction, in each Centre, of a routine maintenance culture. By this the Hospital Managements allowed all the RIT systems to undergo professional functionality auditing and thorough system servicing by qualified RIT in-country technicians once in every 6 months. Some employees of the hospital's engineering department were deployed to be trained to assist in the technical upkeep of the recycled systems. This programme ensured the replacement of any damaged or damaging part of the incubator before this could lead to the system being run to a stop.

7. Paediatrics incubation technique course

It was discovered that generations of medical students and staff had come and passed on from the Units without ever practicing with a really functional incubator. This created generations of staff who knew no better than how to crudely improvise cages to do the work of an incubator. This hence meant an absolute lack of the fundamental knowledge of how to operate and nurse babies in proper incubators. There was initial 'general' staff training on how to operate the newly recycled systems. This basically familiarised the systems to the nurses, clinical staff and the engineering technicians, demonstrating the various assemblies of the machine and how it worked. The course was basic enough to introduce the system with the assumption that the attending staffs were already trained in various aspects of

new-born management including incubator care. Over the succeeding months and across the peculiarities of the various participating hospitals in the region, there was continuous monitoring of how the nursing and clinical staff (care providers) attended to the patients with the incubators. Practice errors were thus identified; building up what was later to form the contents of a proper course work that would treat the fundamentals of incubator care in the tropical climate. This was to collate environmental, socio-cultural, human and technical factors as observed to design an elective course to demonstrate a customised approach to neonatal incubation within the climatic setting. This was to demonstrate to the attending care-providers how various wrong practices could have contributed to the mortalities in their Units. The second aspect of the course concentrated on educating participants on the 'dynamics of neonatal thermoneutral control' based on the best practice approach for achieving a steady body temperature for babies in incubators in the tropical climate. This two-graded elective course coined 'Paediatrics Incubation Techniques' thus had level 1 as 'fundamentals of neonatal incubator care' and level 2 as 'dynamics of neonatal thermoneutral control'. The general aim of level 1 was to apply theories and on-the-spot practical demonstrations to explain the basic physics of incubation and how the incubator achieved this. This also demonstrated how familiar wrong practices could have prevented the incubator from properly achieving its aims thereby delimiting the overall neonatal care quality. Level 2 was a short course that taught participants how to interactively set and re-set the incubator set-point to avoid the common confusions encountered when using the incubator to thermally stabilise the baby. The contents of these courses are briefly set out below.

7.1 Fundamentals of neonatal incubator care

The course was started with an introductory segment that was aimed at making participants to understand the general make-up of the incubator. This presented its features and mode of operation in a way as to simplify any complexities that would make care-providers see this as a mystery machine. This emphasised that Newborn babies were precious and generally delicate while the premature, among them, were much more delicate to nurse, especially during the first few days of their arrival. The premature baby, during the first few days of its arrival, needed above every other thing, controlled and regulated warmth that could provide it with a comfortable environment in its struggle for survival. The Incubator, in doing this job, becomes the obvious best friend of the premature baby during this period. A mishandling of the Incubator would mean everything DANGER to the precious premature baby inside it. Therefore a carefree attitude towards an incubator on duty could expose the child to suffocation, electric shock and many other dangers that could claim its life. Hence it was necessary that every nurse and clinician was adequately informed and trained before he/she could effectively nurse a baby with it. This emphasized that the incubator was precious and delicate just like its best friend and hence must be handled with care.

The course module explained some differences in designs of infant incubators, describing these as diverse and versatile, pointing out probable constraints necessitating the design variations. Although there is a generally acceptable basic programme of operation of an incubator, different manufacturers enhanced their designs over others with automation technology that improved their values. Modern designs incorporate microprocessors that aid automatic operation of the machine, enabling it to do much more than what older analogue and hybrid systems could do. The microprocessors fostered advanced artificial intelligent systems that regulated the humidity of the incubation chamber or neonate's

compartment. Some apply affixed probes to independently monitor baby's temperature, breathing, heartbeat rates and weight-gains.

The module explained why some infant incubators were designed as "Transporters" or "Rescue" Units; discussing the kinds of "Power Sources" that keep the system functional whilst on transit. The power source could be assemblies incorporating a lead-acid accumulator (car battery) or rechargeable uninterrupted power supply (UPS) units. Transporter designs are used for ambulatory services, i.e. to move premature babies, for example, from the labour room to the neonatal intensive care unit. During such transport operation, the machine power source would be switched to battery or UPS. In cases where the baby arrives in a distant hospital or maternity, the transport incubator could be inter-phased with the car or ambulance electrical systems for operation throughout the drive or flight. More sophisticated transport incubators are designed with integral neonatal ventilators for life support and to minimize the possibilities of successful apnoea attack. Transporter units are designed to also make use of the conventional electric mains supply during normal operation in the ward. Diagrams and photos of different models of transport incubators were used to buttress on the diversity of transporter designs where none was physically available in the hospital.

The ability of the incubator to make artificial (programmed) decisions was explained. This facility is installed in incubators at different capacity levels depending on the taste and design constraints of the manufacturer. The intelligence is mostly installed take care of

- a. Incubator over-heating through 'air' temperature sensors or baby over-heat through 'skin' probes on baby.
- b. Electric Current leakages which can cause electric shock and hence harmful to both the attendance and the premature baby inside it.
- c. Humidity control for the comfort of the baby. Most of the earlier designs incorporated manually operated humidity controls.

Other primary allowable design capabilities, either automatically operated through its artificial intelligence or manually were explained. These included Weighing features for checking baby's weight gains; Oxygen supplies through inbuilt oxygen concentrators or direct feed through independent oxygen cylinders or supply plants. The need and necessity for incorporation of cooling facility in tropical incubator designs to aid heat extraction for climatically overheated incubators was also explained.

Participants were also taken aback in history to trace the origin of modern neonatal incubation. This segment of the course endeavoured to show the progress in the development of the ideas and technologies that led to the design and production of the modern systems that could be seen today. The contributions of early players were discussed, including: the early Egyptian applications, the 1588 Giovanni Battista della Porta's idea, the 1609 Cornelius Drebbel's 'Athenor incubator' with thermostat, the 1770 John Champion's London design and patent of 1846. Other pioneering works examined were those of 1837 work of Dr Crede of Leipzig, Odile Martin's 'Couvercle' at Paris Maternity Hospital and the remarkable 1896 Earl's Court exhibition in London [Drebbel, 2011; Neonatology on the web, 1897].

The course isolated different basic assembly modules of an infant incubator and practically demonstrated these features to intimate students on the operational links of these to achieve regulated warmth for the baby. This includes: (a) Power source/input assembly (b) Electromechanical/Electronic compartment (c) Compressor/fan assembly (d) Thermal generation assembly (e) Humidity assembly (f) Incubation chamber/Neonate's

compartment (g) Thermostatic assembly and (h) External communication assembly. Cartoon illustrations were applied in some instances to ensure fair understanding of the ideas behind these various assemblies (Figure 6).

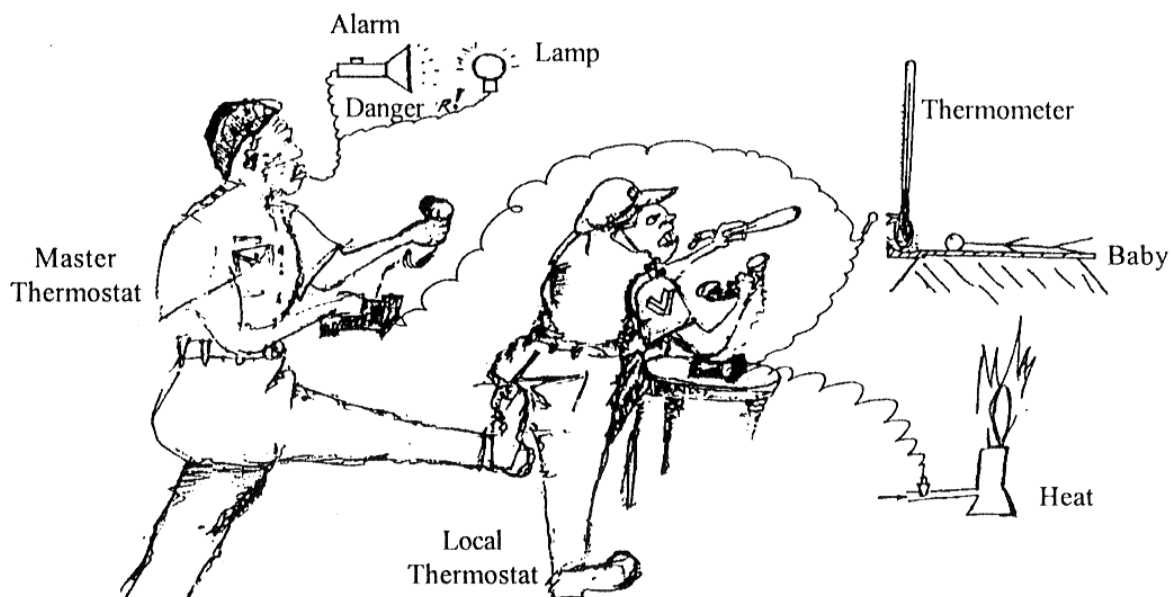


Fig. 6. Cartooned illustration of thermostatic operation

[This assembly is the thermal policeman of the incubator. It controls and gives the thermal generators instructions on when to supply heat and when to stop. It always checks up the temperature of the incubation chamber and compares it with the operator's input (set point). The thermostat's 'ON and OFF' or 'REDUCE and INCREASE' commands to the thermal generators help it to keep a check and guard against an under- or over-shoot of incubation temperature. It does this by what is known as "feedback control mechanism"]

7.1.1 Operational safety

This was a special segment of the course taught in relation to the neonate, the care-provider, the immediate nursery ward and the incubator itself. Necessary steps for the care of incubator were examined so that participants would appreciate the conducts that were required for their systems to remain functional and hygienic. Some of these were:

- a. Preventive Maintenance Culture (PMC): This was an important routine that every newborn intensive care manager was encouraged to imbibe. The PMC is a practice of keeping the incubators and all other neonatal equipment in the neonatal intensive unit under a regular and routine technical check by qualified service personnel to ensure safety and avoid frequent breakdowns. Such breakdowns can occur at odd times especially when the services of the machine are most needed by a neonate. The PMC helps to put the systems in regular six or four monthly technical check-ups and performance auditing.
- b. Cleaning: There was need for a regular cleaning and dusting of the machine outer casing everyday so long as the machine was in use. A thorough 'in and out' cleaning is very important before the machine is put into use after a long time of being parked. Various tested locally available disinfectants were recommended for use during such cleaning exercise. The cleaning of the incubators was discouraged from being grouped among the relegated menial jobs given to recruited 'ordinary' people to do. These often

low-paid casual workers were recruited to mop floors, clean windows and dust chairs. These also went ahead to handle the incubators, often with neonates inside, the same way as they cleaned chairs using same filthy and smelly rags. What a perfect way of introducing bugs that reduce neonatal survival and also cause damages to the incubator! The course stressed the need for hygiene around the neonates and the incubators and to keep off such infection vendors as outside visitors, improperly masked staff and mothers. Participants were encouraged to use their improved understanding of the neonatal microenvironment during the course to ensure effective cleaning standards that would be professionally acceptable.

- c. **Mains Input:** There was always insufficient power sockets on the walls of nursery wards to take up all electrical appliances required to be on at the same time. This was an observed failure common to all participating neonatal centers without an exception. This deficiency in the nursery electrification often causes care-providers to multiply power ports by the use of 'cabled extension'. Unfortunately, this indiscriminately run all over the place, staying in the way for movement and potentially posing the hazard of a staff tripping over them. This might result in injury to the staff or the baby such may possibly be carrying. The use of extensions causes care-providers to innocently overload these cables and the host power sockets causing electrical sparks and shocks, endangering lives and damaging equipment. This was therefore labeled a hazardous and unprofessional practice that must be discouraged. New wiring designs were proposed and implemented in each Centre to correct this deficiency.
- d. **Humidity Reservoir:** The care of the humidity reservoir was a segment that highlighted on the effective management of the incubator humidifiers. This explained how the reservoir might be kept from becoming nursery for infection-causing micro plants and organisms. Hence, humidifier tank must be drained of water whenever the machine was discharged of a neonate and kept dry if not in use. The tank should however be refilled with distilled water whenever the machine was to be used again. Water could be boiled and stored in a clean plastic container for use as an alternative to the use of distilled water if unavailable.
- e. **Thermometer:** The operator must closely monitor the temperature of the incubator with the thermometer provided to probe the microenvironment. This helps to notice when the temperature might be indicative of unfavorable condition inside. This is important especially for cases when there is a thermostatic assembly failure.
- f. **Voltage Stabilizer:** Use of single incubator-specific automatic voltage regulator (AVR) sets was introduced and encouraged to be applied. Erratic, poor quality and incessant power failures in these tropical countries often exposed the incubators to power surges and under voltage supplies that crippled their effective function (Figure 7). The functional inadequacies of this phenomenon were demonstrated diagrammatically to enable self-appreciation of the problem by the trainees so as to have personal drives to protect the systems during use.
- g. **Earthed Lines:** Trainees were encouraged to carefully inspect incubators being delivered for use before acceptance. It was important to reject incubators with obvious electrical hazards such as un-fused systems and the absence of the 'earthing line' pin (E) on the plug head, whether the system was a new product from a supplier or repaired system from the maintenance workshop. Cartooned illustrations were used to demonstrate how these related to the general building earthing and how these served as safety devices to protect baby and care-providers from 'static' and 'mains' electric shocks (Figure 8).

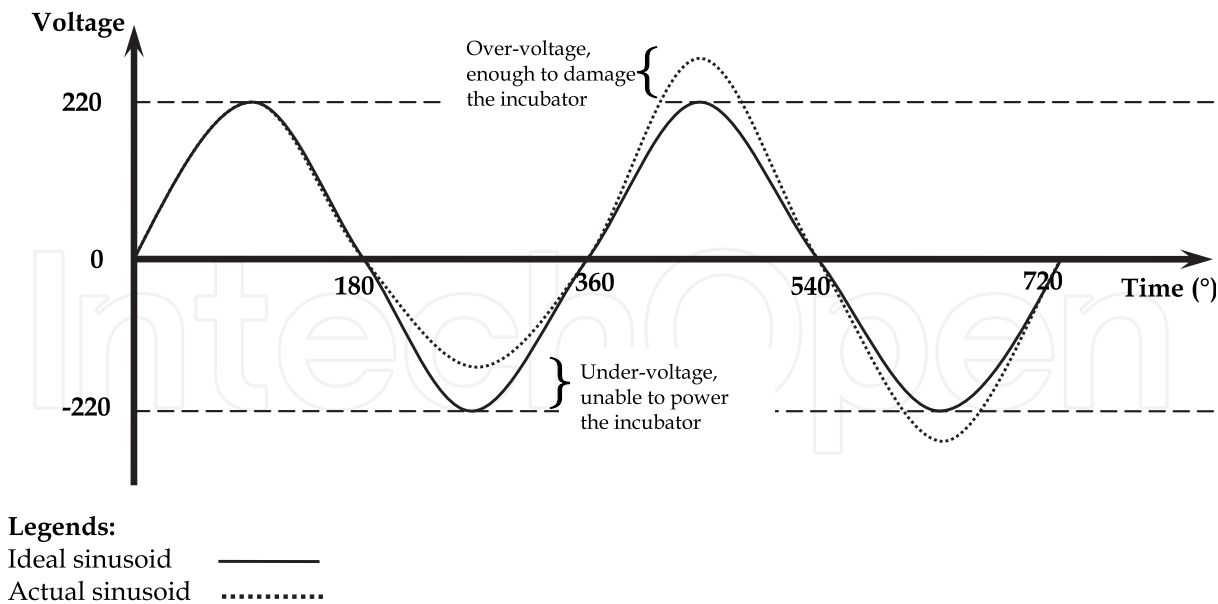


Fig. 7. Exaggerated sinusoids illustrating unsteady power supply

[There may be need for a voltage stabilizer set to run an incubator in these countries, especially for modern microprocessor based systems that might not operate with deficient power supplies. However, it must be noted that at adverse, erratic power supplies as has been witnessed, the stabilizer also stood in danger of being blown up together with the incubator it was supposed to be protecting. At this condition, if need be, it was necessary to power down the incubator.]

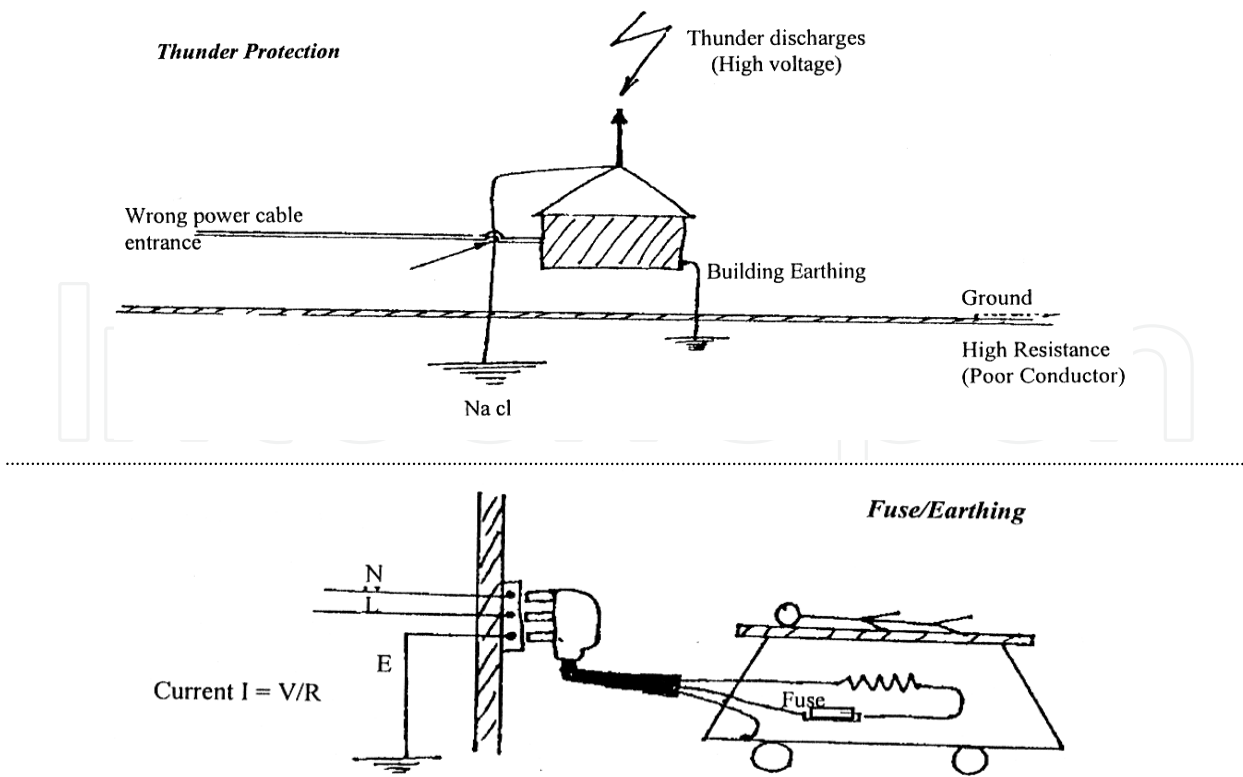


Fig. 8. Cartooned illustration of earthing line

[There must be a regular check of the effectiveness of the electrical earth conductor of the building that is housing the incubators. Improper 'earth' conduction or failure of the electrical earth line is an electrical hazard and can cause such accidents as electric shock to the baby or attending clinician. Poorly installed earth conductor such as shown in the diagram can cause interference of thunder discharges with the power supply to the machines. This can lead to damages to the incubators and other systems. Inexperienced contractors as has been noted can wrongly pass the copper conductor of thunder discharges directly over an electric cable that supplies the building. The interference that resulted from this in one occasion destroyed all connected appliances in the nursery.]

- h. **Socket Pin:** Burnt wall sockets and plug head were observed being used to power incubators and appliances in the nursery irrespective of their conditions. The dangers of this practice were communicated and the continuous use of incubators with broken or partially burnt plug heads was discouraged. Hence, every broken power plug, burnt socket or wrong fuse must be changed before these were used to power the incubators. Figure 9 shows a couple of dangerous plug head/socket applications captured during usage.

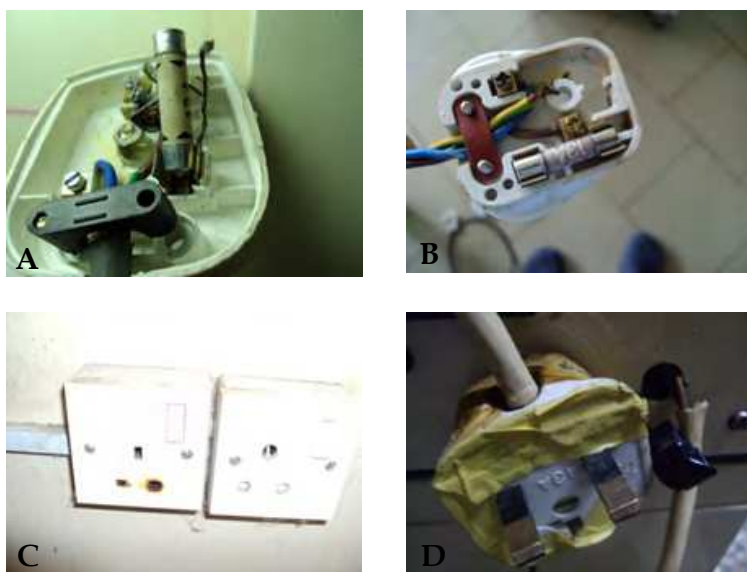


Fig. 9. Unsafe socket and plug heads (A) plug head with hair wire instead of properly rated fuse (B,D) broken plug head with missing earth-pins (C) burnt socket

- i. **Operator:** Unit Heads were encouraged to ensure that untrained operators or nurses should not be allowed to man the machines until these were properly lectured on how to use them to provide effective care for the neonate. This pointed out the dangers of wrongly operating an incubator and how this might turn around to destroy the baby rather than saving it.

7.1.2 Incubator overheat

It was a common event across all centres to observe practices that led to an incubator overheating beyond their set point values. Such situations often resulted in neonatal hyperthermia for the babies inside the incubators. It was therefore necessary to carefully study how the identified conditions and practices resulted in the malfunctioning of the

incubators. A segment of the course module was dedicated to this, emphasising possible remedies as peculiarly applied to each Centre. The identified causes were of two types, namely externally induced warming and locally induced warming. External warming of the incubators happened as a result of wrong positioning of the system within the nursery building or close to other heat generating gadgets in the same rooms. The consequence of external sources of incubator warming is not necessarily a new discovery as this has already been commented in the literature (Lyon, 2004). However there was no practical evidence of a working knowledge of this in any of the Centres. Related errors were therefore identified, studied and included in the course module to educate users on how their habits were contributing to the situation. Few of these are briefly explained below.

- a. Incubator access doors: Wrong usage of the incubator access doors and portholes was the primary cause of locally induced extra warming of the incubator. Attendants were often observed to carry out long procedures on the neonate right inside the incubators with all portholes or access doors left wide open whilst the incubator was still on (Figure 10). Such procedure might start at a time when incubator had already attained and maintained the set-point value. Opening of the portholes for a long period of time compromises the integrity of the microenvironment by a sudden drop in temperature within the chamber. This happened as a result of the nursery cooler air that uncontrollably rushed into the incubator chambers.



Fig. 10. A long clinical procedure being carried out inside a functioning incubator

The incubator air probe senses the drop in the chamber temperature and sends signals to the controller. This makes the thermal generators to increase heat output in attempt to counter the losses through the open portholes. This condition could cause the thermal generators to maintain an unnecessary 100% heat output for the period of the procedure without this being noticed because the extra heat was being fed to the wider nursery. However, soon

after the procedure has been completed and the portholes and access doors closed, the extra heat already generated within the thermal compartment is then concentrated in the recovered microenvironment overshooting the set-point value. The incubator intelligence would sense this and automatically withdraw heat generation. However it would take a long time for the accumulated chamber temperature to fall, within which this effect could instigate neonatal hyperthermia. Following from other studies, the literature has commented that the use of open bed is more convenient than the closed incubator during special procedures such as endotracheal intubation or arterial catheterisation (Tunell, 2004). Procedures requiring long period of time was advised to rather be carried out on a resuscitaire or 'work-bench' under a radiant warmer as this also allows the clinician enough space to work. Alternatively, the incubator should be switched off if such procedures must necessarily be carried out inside the incubator. This overheating effect was also practically demonstrated during normal working periods when such errors occurred and this helped to accelerate a change in this attitude of workers within the Centres. This practice was also identified to be unhygienic as many of the incubators were observed to contain various leftover items of work materials such as syringes, needles, wrist bands, cotton wool, plaster, sample bottles etc (Figure 11). A currency note and caps of water bottles were also items recovered right inside the incubators in some cases.



Fig. 11. Items of clinical and other materials trapped inside humidifier/heater chambers of three different incubators on active service.

- b. Radiant warmer: Literature has previously pointed out external heat sources that could contribute to incubator overheating (Lyon, 2004). All through the observatory period of the present work, Centres never paid attention to incubator positioning

relative to open radiant warmers. This hence contributed a great deal to the re-occurring cases of incubator overheating and neonatal hyperthermia for systems located very close to warmers. Causes to this were mistaken by attendants to be local to the incubators until these were practically demonstrated during the series of trainings to show how the incubators displayed 0% local heat output whilst the chamber temperature was steadily rising. The practice of incubator positioning in these Centres were hence modified, avoiding incubators to be located next or very close to the location of open radiant warmers.

- c. Phototherapy lamps: Neonatal jaundice is a widespread disease simultaneously treated whilst baby is being incubated. Therefore it was common to observe various kinds of phototherapy machines set over incubator canopies. Many of these often locally-produced systems operated on conventional household fluorescent lighting tubes. These deliver very high intensity of heat across the canopy to the baby, uncontrollably overwarming the microenvironment. The operating heights of these systems were often not adjustable or professionally fixed to avoid the consequent induction of incubator overheating and neonatal hyperthermia. It was hence demonstrated that the use of scientifically recommended phototherapy light tubes would ensure effective outcome without compromising baby's thermal stability. Constructions to adjust the operating heights of the local systems were recommended and carried out, especially when lack of spare parts or poor financing was the cause of resorting to the make-shift systems.
- d. Nursery windows: There seemed to be no guiding rule for positioning an incubator in the nursery as some of these were placed directly behind windows. High heat intensity of sunlight gained easy direct access into the nursery through the glassy windows. This takes over the warming of the microenvironment through the transparent canopy. This uncontrollable external heating was often the cause of incubator overheats and hyperthermia during the day times. Incubators were therefore discouraged from being placed against glassy windows as much as possible within the nursery. Alternatively, appropriate window blinds that were able to minimise the solar radiation were fixed; these could be chosen to be drawn when necessary.
- e. Nursery walls: Incubators were recommended to be placed no less than 45 centimetres from the nursery walls. This minimised the adverse effect of heat radiation from the overheated walls by the sun. The structural building pattern for new-born wards did not have any special consideration to minimise radiant heat storage. The observed poor designs easily made the walls work like a capacitor, being recharged by the sun from the outside during the day's heat. This retained the heat which was later discharged into the nursery, uncontrollably warming the incubators and babies in cots. This 'capacitance effect' was identified to be responsible for the common cases of periodic feverish attack on most babies in the ward. Though not yet reported in any medical literature, this experience is prevalent in all the Centres that participated in this study. This was observed to begin in many of the Centres at different times during the 'pm' periods of the day. This uncontrollable 'evening fever syndrome' would often confuse care-providers as they struggled to narrow the feverish event to any particular pathological or clinical cause. Most Centres were also observed to resort to using water to sponge babies to lower their temperatures. Others opened all incubator portholes and doors in attempt to lower temperatures thereby exposing neonates to the open environment and all kinds of air-borne infection vendors.

7.1.3 Further common errors

There were other commonly identified errors that might have contributed negative impact on the general wellness of the neonates, impoverishing practice outcomes. These were studied as applied to the local setting, trying out and proffering some coincidental effective solutions. Some of these were:

- a. Humidification: Adequate humidification of the microenvironment has been said to enhance effective neonatal incubation (Silverman et al., 1958, 1963). Humidifier assembly is therefore a basic feature of a standard infant incubator. In most incubator designs this is located beneath the mattress tray at the covered lower aspect of the machine. Humidifier fill-ports from which this could be refilled or drained of water are usually visibly located in front or at the sides of the incubator for easy access. The often harsh climatic weather brings about a very low atmospheric Relative Humidity (RH), as low as 20% in the northern parts of Nigeria. It could therefore be a serious clinical challenge to keep baby adequately hydrated during resuscitation and neonatal nursing if this facility was not properly applied. The practice of running an incubator with dry humidifiers whilst baby was inside was a common failure observed in all the Centres at the beginning of this project. Quick staff interviews revealed that some attendants were not aware of any humidification facilities in incubator designs. Many of those aware of this confessed never bothered or remembered to add water to operate this. Many practical incidents occurred in Centres that perfectly assisted as good traditional events to convey the reasons behind these inevitable scientific procedures.

On one occasion during a whole day consultation in one of the collaborating centres, a certain incubator was running at a set point of 35.5°C. It was on a sunny dry 'harmattan' period, described as a West African season of hot, dry and dusty trade wind that normally blows from the Sahara during the month of November, carrying large amounts of dusts out over the Atlantic Ocean (Wikipedia, 2011; Britannica Online, 2011). The afternoon of the said day was about 35.2°C outside air temperature, nursery room temperature and RH of 34°C and 22% respectively. About half an hour later the same incubator with the same 5-day old baby was observed to have been reset to 37°C. The set-point of this was again, another 1 hour 45 minutes later seen to have been increased to 40°C. The system was a 'dial-knob control', mercury meniscus-guide thermometer, Narco Isolette Airshields incubator model C86 at the SCBU of UPTH Port-Harcourt. Upon the observer's request, baby's skin temperature at that instant was measured to be an extreme hypothermic 33.2°C. The baby was said to have been on a steady temperature decline over several hours and throughout the period the incubator set-point was being raised. There was the presence of obvious clinical confusion as the attending clinician seemed to have eliminated some possible reasons for this situation and expressed fears of losing the baby. This true situation recalled similar events that had been observed in other Centres across the country. The incubator humidifier was at this point checked and discovered to be completely dry. As this called for emergency, available 'clean' water was called for and introduced, incubator set-point arbitrarily lowered to 37°C and humidification set at 'maximum' mark. This was also advised for the rest of the incubators in the ward as these were also being operated without functioning humidifier. To the amazement of the clinicians and nurses on duty who got involved in the frenzied situation, baby's condition dramatically reversed. Baby started to improve, gaining skin temperature after only 10 minutes and reaching 36.2°C in 35 minutes. This obvious wrong practice culture at UPTH at the time was to change forever as the science behind the drama of this event was explained to the wider audience of the Unit's care-providers.

Etiology: The science of molecular equilibrium in an open environment expects molecular migration from an area of higher concentration to a lower one. This general law was also expected of a microenvironment with very low RH as in this real life example. As baby was incubated 'naked', i.e. without clothes or wrapping, the microenvironment was a continuum with the porous-skinned neonate. This meant that baby, having more water than the immediate surroundings, was dehydrating by losing water to a thirsty atmosphere as the microenvironment sought to reach its saturation. Unfortunately, this instigated another general law of basic physics that 'evaporation causes cooling' and manifested in the dropping of baby's skin temperature. The subsequent practice response of the increased incubator heating made things worse because the microenvironment became dryer and hungrier for more water thereby exacerbating the baby's condition. Hence, this practice was never going to improve baby's condition under the present circumstances. Introduction of water in the humidifier chambers quickly saturated the microenvironment's atmosphere, reversing the concentration gradient of water molecules in the continuum in favour of the baby. As baby gained moisture and headed for saturation, evaporation immediately seized and neonatal cooling stopped. Hence, baby began to regain thermal stability as it retained the moderately supplied warming. It was possible for other neonatal complications to result in baby's loss of temperature as this; however, practice experience in this climatic region showed that elimination of possible causes should start with a check on humidification.

A near opposite of this occurred during heavy torrential rainy season that was also common to this climate, around the months of June. This would leave pockets of surface puddles scattered all over the area due to poor drainage systems. The atmospheric humidity of nearby neonatal nurseries had been measured to reach full saturation affecting the functioning of certain models of incubator such as the Vickers models 59, 79 and 77. The humidity control mechanism of such systems did not allow full stoppage of moisture supply to the microenvironment, especially when the humidifier contained maximum water. The reluctance of the wider nursery atmosphere to accept escaping moisture from the incubator soon led to saturation and condensation within the inside walls of the canopy. The resulting misty covering, often referred to as 'steaming' by the care-providers, blinds the see-through canopy, confusing the less experienced workers. The direct effect of such over-humidification on the wellness of the neonate had not been fully studied within the present project, however, literature points to a possible neonatal discomfort and a poor overall outcome (de Carvalho et al., 2011). A coincidental practice remedy to this was to fully minimise the setting of the humidity control followed by a possible drastic reduction of the humidifier water level.

- b. **Incubator overcrowding:** This term refers to the wrong practice of putting more than one baby into a single functioning incubator, a common method initially observed in all the collaborating SCBUs (Figure 12). There are a lot of imaginable consequences of this practice on the general outcome.
 - i. This can easily lead to neonatal cross infection among the inmate babies and can potentially cause the loss of all of them to the same infection outbreak.
 - ii. This makes it absolutely difficult to regulate the incubator to suit all babies at the same time. Neonatal thermoneutrality is supposed to be a patient-specific application because thermal responses to the same environment can rapidly differ among neonates. This practice hence has the potential of saving one baby whilst adversely choking the rest to death. Therefore this must be avoided where possible, even for a possible lower-risk carrying cohorts of a multiple-birth.

- iii. There is a potential risk of mistaken administration of the wrong medication to the wrong patient by the often over worked nurses on duty.
- iv. This increases the dangers of possible fall through less secured incubator portholes as reported by Health Devices (2010).



Fig. 12. Two babies sharing a single incubator.

This wrong approach was reported to be due to inadequacy of functional systems to independently support all needy babies, mostly blamed on poverty and poor funding. The seemingly moral reason of giving equal share to all needy babies as argued by some care-providers must be seriously weighed against the above consequences and for the sake of clinical hygiene.

7.2 Dynamics of neonatal thermoneutral control

This was the level 2 aspect of the 'Paediatrics Incubation Technique' course. The content of this aspect was drawn from lots of observed unscientific manner the incubators were operated during neonatal nursing. There was absolute lack of knowledge or any algorithm on how to re-regulate the incubator set-points based on the state of the neonate to achieve a physiological thermal equilibrium for the baby. Modern incubation techniques rely on algorithms that have been discussed in the literature stemming from the knowledge of 'central or core temperature' (t_c) and 'peripheral temperature' (t_p) of the neonate (Lyon and Oxley, 2001). This technique requires the probing of the baby's skin temperature at two separate spots, notably the t_c from baby's back, in-between the scapulae and the t_p from the sole of baby's feet. This technique primarily measures a differential blood temperature (t_d) based on blood stream closest to the cardiac exit (chest level) and farthest travelled stream (foot level); $t_d = f(t_c, t_p)$. Instantaneous values of t_c and t_p are applied to proposed equations and situations to obtain the appropriate marginal values for upward or downward resetting of the set-point (Lyon and Oxley, 2001). The proposed equations and resetting algorithms are theoretically sensible and supposed to be practically helpful for application in any setting of clinical practice. However, there were observed difficulties in its clinical usage in

the present situation as most of the clinicians and nurses would require a standby calculator to work out the values of t_d each time the incubator was to be reset. This soon became more frequent than to be tolerated by the often too busy few staff on shift. This difficulty was made worse by the high volume of neonates that were usually on admission during the shifts. In probable recognition of this difficulty, modern STA incubators such as the Draeger Caleo system are designed with a similar algorithm inbuilt in them. Therefore it is possible to permanently affix the temperature probes on the designated portions of baby's skin for the incubator to automatically and appropriately reset the incubator when baby's condition changed. Unfortunately, over 97% of the incubators in use in the studied tropical region were of older generation of incubator systems, requiring manual application of this modern algorithm by the attendants. On-the-spot monitoring and study of how attendants operated the few STA systems was carried out. The findings however raised new concerns for the consequences of inaccurate application of the temperature probes.

7.2.1 Dangers of 'skin mode' control

The presence of some skin-mode servo-controlled modern incubators and open warmers should have been a welcomed advantage for the few Centres that had them. However, a sound knowledge of the working principles of such advanced systems was extremely crucial for their services to produce effective automatic neonatal thermoneutral control. Unfortunately, our initial practice observations in these Centres showed insufficient understanding of these as has been expressed in the literature (Perlstein et al., 1997; Dollberg et al., 1993; De La Fuente et al., 2006). Users knew little about the possibilities of true skin temperature attenuation as the thermistor probes placement was always improperly done. These reported their previous experience and fears when baby's temperatures were noticed to soar whilst incubator displayed a desired 36.5°C. These could not effectively interpret the reason and hence resorted to manual control via 'air' mode. It was reported that some instances produced serious consequences of neonatal hyperthermia before baby's ordeal could be discovered. Tunell (2004) pointed out the complexities of the 'servo control' technique and suggested the use of manual regulation during the first days after birth. The important steps and assiduous care required to ensure that such automatic machines did not pose any threat to the life of the babies might have been stressed in the working manuals or by a trained company representative. However lack of the presence of quality professionals from these companies does not allow this. Users are often left at the mercy of common market traders, with no professional understanding, who act as middlemen or vendors for the big companies in the developed countries.

7.2.2 Handy approach

Sophistications and cutting-edge technologies are good, especially in developed countries where expectations compare to the scientifically advanced culture. However, as relates to West Africans with a different culture of poverty, illiteracy and underdevelopment, how do we communicate this sophistication in a sustainable manner? The primary goal of any standard was to save the highest possible number of needy neonates within the limits of poor funding and manpower. A culturally compatible approach would therefore be (1) clinically functional (2) relatively non capital intensive (3) highly simplified, locally-sustainable technology; operational techniques must be (1) easy-to-remember (2) simple for quick mental evaluation of control parameters (3) based on simple but functional

algorithms. These factors guided the development of the 'handy' approach currently being used in all the collaborating Centres. This was a simplified operational algorithm for achieving thermal stability in neonates. A recent follow-up study reported that over 80% of applying nurses believed that the usage of the technique was a boost to their practice enthusiasm [Amadi et al., 2010].

Principles: The handy approach might not be the best technique ever used but this was definitely better than the unscientific 'trial and error' methods observed at the inception of this project. This was developed by a long study that paid very close attention to the worst case scenarios such as the weakness of an 'extreme preterm baby' in an 'extremely harsh weather' of Nguru town, Nigeria. Nguru is a north-eastern ancient city of Nigeria notable with up to 47°C ambient temperatures during certain periods of the year. One of Nigeria's Federal Medical Centres (FMCnguru) was located in this grossly under-developed town. During the periods of these experiments approved by the FMCnguru's ethical committee, informed consents were obtained from mothers that were happy to permit the extended neonatal observations required for the study. The allowable standards for neonatal body temperature in most Nigerian neonatal centres including FMCnguru was a lower-upper limits of 36.5°C-37.4°C, measured from the axilla. Baby's thermal reaction to prevailing room temperatures were noted and compared to how volunteer healthy adults responded to the same harsh weather. Baby's skin temperatures behaved differently with those of the adults as these were observed to be always equal to the room temperature even when this increased to 43°C or decreased to 34°C whilst the adults maintained a constant range of 36.2°C-37°C all the times. This pattern was not exactly the same with higher birth weight and older postnatal age babies. Although such babies were all the same observed to be hyper- or hypothermic during these periods, their body temperatures were slightly lower or higher than room temperatures respectively. The local responsorial procedure at FMCnguru during high ambient heats was to sponge babies with water to minimise hyperthermia. Based on these findings, it was assumed that the neonate was very likely going to become hypothermic or hyperthermic depending on the relative overheating or under-heating of its host incubator. A neonate's thermal equilibrium set-point was therefore defined as the incubator air-mode set point that thermally stabilised a neonate to a body temperature of 36.5°C-37.4°C; incubator being appropriately humidified. The mid-point of this range was set at 36.9°C and used as a target for neonatal stabilisation. Therefore a general guiding principle for restabilising a deviating neonate was to increase or decrease incubator set-point value by an amount equal to baby's deviation from 36.9°C. This also demanded a compulsory recheck of baby's situation at intervals of no more than 30 minutes until baby re-stabilised. This was to allow enough time for the incubator to achieve the new set-point and for the baby to fully respond to the new changes, incorporating a possible neonatal cyclic temperature changes described by De La Fuente et al (2006). A disease process such as infection would be suspected and investigation initiated if baby's situation failed to respond positively to these changes after the 2nd cycle. It must however be first established that hyperthermia was not due to any domineering external warming of the incubator as described in section 7.1.2 of this chapter.

In quick easy-to-remember steps, the handy approach sets a good stage for the admission and systematic management of a neonate in an incubator thus:

- a. Feeder Unit alerts SCBU: At the inception of this project the SCBU of most centres had poor or no existent system of pre-admission communication with feeder departments

such as the labour-ward/theatre for the in-born babies and any available reception unit for referral neonates. Therefore there was always a routine of frenzy and chaotic emergencies at the sudden appearance of an unexpected baby with a group of panicking adults. The confusion often created distracted the normal work flow of attendance on the nursery inmates. A standard of 'feeder unit alert' was hence established mandating a pre-admission alert with expected arrival time (EAT). A fair knowledge of the EAT for a prospective inmate allowed the SCBU management to make adequate preparations and properly assign respective duties to the attending staff in good time for the arriving baby.

- b. Designation and readiness of the expected incubator: Following feeder unit alert, preparations and provisional designation of duties would start. The expectant incubator was the incubator chosen to host the expected baby upon arrival and after all the admission protocols and possible initial clinical routines has been completed on a resuscitation table. The steps for preparing the expectant incubator was: (1) Cleaning with a standardised disinfectant solution of a combination of antiseptic fluids and water, normally referred to as 'carbolisation'. The hood and mattress tray with all the interior of the canopy were thoroughly disinfected during this procedure. (2) Fresh cover spread was laid on the mattress and access portholes requiring replaceable covers were covered with fresh sterile blinds. (3) The humidifier that should have been completely drained of water after the last use was then re-filled with the appropriate incubation water. This was distilled water or in the alternative 'boiled and cooled' water. Reservation of the alternative incubator water was practiced provided this was done in a plastic container as the use of metal containers could generate rust and contaminate the water. (4) The incubator was then switched on. (5) Oxygen in-line supply was connected and tested for function. The supply was then turned off and kept on standby. (6) A provisional set-point for the incubator was fixed at the lower limit of the neonatal clinical range, i.e. 36.5°C. It was necessary to keep the provisional set-point closer to normal body temperature as the baby's point-of-admission temperature was yet unknown, whether this was going to be within acceptable range or not. (7) The incubator was then allowed to run to achieve this set point in good time before baby's EAT.
- c. Admission, resuscitation and stabilisation: Upon baby's arrival, all the normal protocols were carried out by the admitting clinician and baby handed over for neonatal nursing.
- d. Start of incubation: Initial thermal stabilisation started as soon as baby was introduced into the incubator. Baby's entrance temperature was checked and noted. Attendants would ensure that baby was securely place on the mattress and all the access doors and porthole covers were securely latched. Opening of all canopy access windows to work on the baby were kept at minimum. Baby's temperature was re-checked no later than 30 minutes after incubation began to confirm a possible re-adjustment of the incubator set-point, to search for the thermal equilibrium set-point.
- e. Subsequent thermal re-stabilisation: This followed the procedure described earlier in this section to find a new equilibrium set-point whenever baby's temperature deviated from the allowable range. Figure (13) shows the guiding flowchart for this dynamics.

8. Externally influenced deficiencies

Gradual elimination of the various identified and rectified SCBU errors has steadily improved practice in the collaborating hospitals. However, there are other highly influential

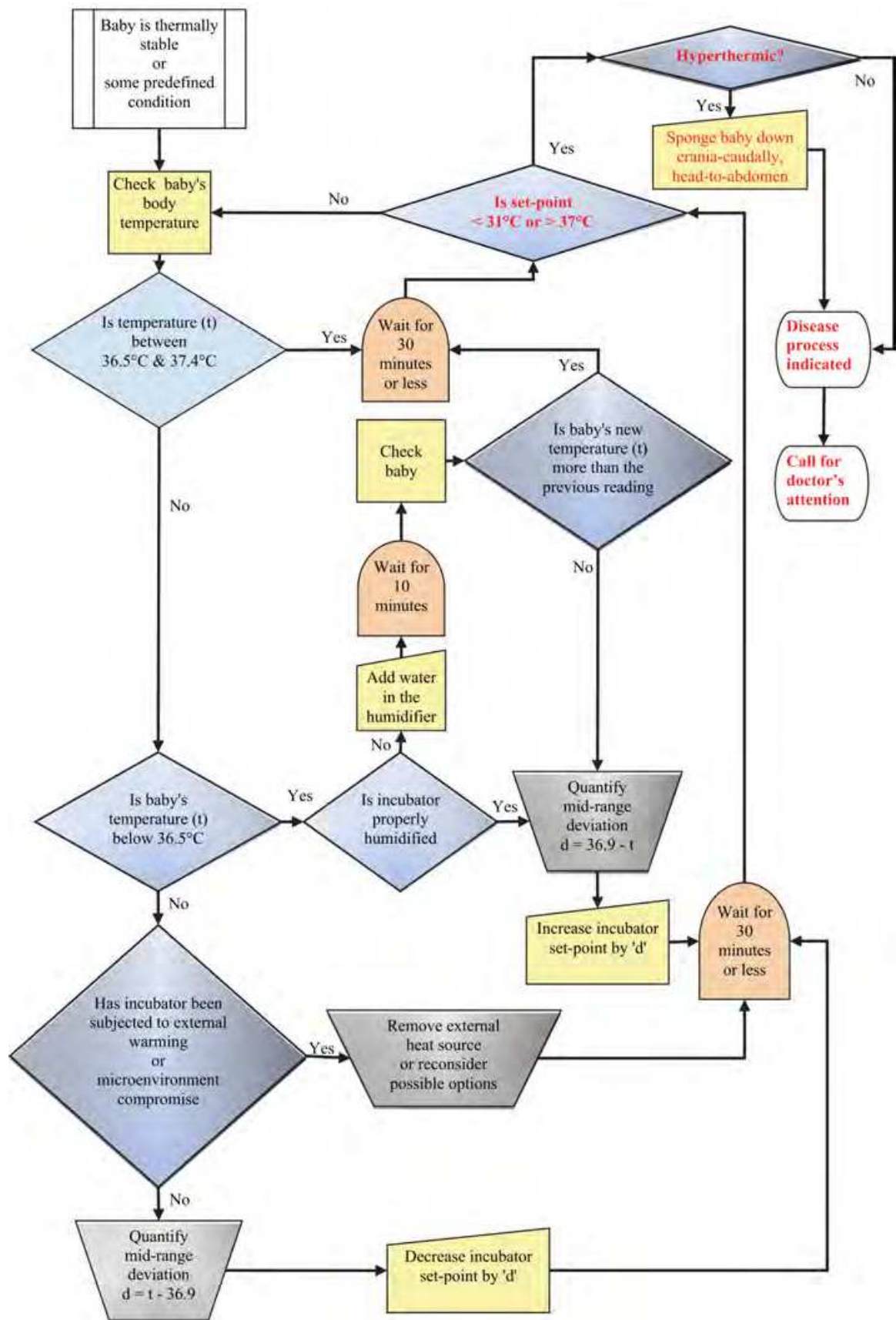


Fig. 13. Thermoneutral control flowchart

external factors that are possibly contributing to lower practice outcome. This category of problems might be beyond the ability of immediate SCBU to correct, hence required the cooperation of the higher institutional management to resolve.

8.1 Epileptic power supply

Inside a functioning incubator and yet wrapped! One would expect that a well-documented and known practice of nursing neonates naked inside a functional incubator would not need to be overemphasised anywhere in the world (Lyon, 2004). However this was initially observed to be one of the wrong incubator applications in the collaborating Centres. Some of the users showed evidence of this knowledge but could not stop because they needed to protect baby from cold stress that sets in upon power failure. However, there were no clear reasons given for this practice during the periods when the system functioned. Uninformed and indiscriminate electric power outages that last for several hours are common to West African countries. Unfortunately, very sensitive units as the SCBU of hospitals suffer from this problem at which point the incubator suddenly fails exposing baby to danger of cold stress and hypothermia. The use of 'standby' generators is widespread but this still does not effectively cover up this deficiency in most Centres. There were also reports of incubator damages due to power surges from malfunctioning generators. Full-sine-wave power inverting technology was therefore considered an option to investigate. A full-sine-wave power inverter system with a cascade of sealed batteries function to convert the DC power of the batteries to AC power required to operate the incubators upon conventional mains power failure. This operates with an automatic power change over system that allows it to stay 'on' to recharge the batteries when mains AC supply is available and switches incubators to draw inverted battery power when mains supply fails. A 5KVA system installed with up to 8 pieces of '12 volts 200 amp-hour' batteries was found to be able to continuously support up to 11 incubators simultaneously for up to 10 hours. This was enough to provide uninterrupted power supply to the most critical neonates in the few Units that could afford to implement this, hence minimising the effect of operating power deficiencies.

8.2 Inadequate nursing staff

The sudden increase in the number of patients seeking to be admitted for neonatal care as reported by Amadi et al (2010) meant that more hands were needed to cope with the present volume of work in each participating SCBU. The Units were hence faced with the lack of adequate manpower and challenges to retain the already experienced ones on employment. External issues of government policies on employment and local administration of the Nursing Department in these hospitals were contributing factors to the challenges. The direct effect of this to the present project was the resulting inability to effectively offer adequate care using all the developed techniques and procedures in this project. Some of these challenges as enumerated below are currently being tackled through engaging the various hospital managements to demonstrate the importance of discriminate staffing of the new-born Units.

1. Maintaining a sizable number of SCBU nursing staff as compared to adult or young-adult wards. Most of the SCBUs are currently having up to 40 inmates on admission at the same time with as few as 3 nursing staff to look after them during some rota shifts. Our current study shows that the quality of attention offered to these babies becomes

clinically unacceptable at more than a patient-to-nurse ratio of 5. This mark is frequently being exceeded, hence calling for urgent review on nurses' deployment to the Units. This has also led to some preventable losses to apnoea as many attacks were not detected early enough to commence resuscitation. It therefore became important to propose and implement the provision of integral digital apnoea monitors on all incubators and cots. These raised audible alarms during attacks, enabling the few nurses on duty to be aware of the points of emergency even whilst they were busy with other babies.

2. Frequent shovelling of experienced nurses has militated against more excellent results from the Centres. It was a common routine in 80% (12/15) of the hospitals to re-shovel senior nurses among all the departments including the neonatal wards. This was entirely governed by the Nursing Department as a measure to allow nurses acquire experiences of how things worked in various departmental wards and happened as frequent as every two years or less. There might be good intentions for this; however, our findings from the present study showed that this was producing a serious counterproductive effect on the SCBU target. Nurses needed to stay in the Units for up to 18 months to fully understudy the new systems and procedures being implemented to positively alter the neonatal mortality as these ideas were completely new to most of them. During this period they would have attended the level 1 and perhaps level 2 of the Paediatric Incubation Technique courses. This has hence frequently created occasions when all three or four nurses on duty were completely untrained newcomers to the new procedures, hence slowing down the progress of the Unit. Minimizing the unequal shovelling of well-experienced and trained neonatal care-givers with inexperienced ones has therefore become a major issue to settle in all the hospitals. A proposal was drawn and negotiated with the various Nursing Administrative Departments of the hospitals to implement a 'neonatal 70-30' agenda whereby their normal shovelling exercise must ensure that 70% of SCBU qualified nurses were specialised or have at least 15 months experience and certified on the course levels 1 and 2. This excluded the numerous yet-to-qualify and short-staying nursing students that must work under full supervision of at least one experienced nurse on duty. This is presently working well and yielding good results in 6 of our 15 collaborating centres. Quantified in terms of incubation hours denied due to system breakdown, and comparing one calendar quarter before and after full implementation of the agenda, this has on the average saved 81% (10,886.4 hours) of the total incubation time lost to system breakdown before implementation. It is evident from these 6 Centres that frequency of system breakdown due to mishandling has dropped, thereby reducing maintenance costs and providing for more babies to save.
3. Compulsory theoretical course (requiring a pass in an end of course test) was initiated and currently being implemented by some of the Nursing Administrative Departments as a prerequisite for posting a new nurse to the SCBU. In the new guideline, resident doctors that were specialising on new-born care were advised to complete the 2 levels of the elective course.

9. Conquering the climate

The conclusions being drawn from the entire project suggest that culture and climate were major forces to conquer in order to realise the MDG target on neonatal mortality. Our on-

going studies at the University of Ilorin Teaching Hospital and the Federal Medical Nguru have identified a number of parameters that could be altered to reduce the negative impact of climate on new-born morbidity. We studied all the nursery buildings at our disposal, these being all distinctively different from each other in design, structure and relative location. The impact of high sunlight intensity as a source of uncontrollable external warming of the incubator was used to identify the parameters that were aiding or preventing the harsh climate. Incubators functioned well, adequately maintaining their set points, when these had absolute control of the warming of their microenvironments. This occurred during cooler periods of the day or the night when the nursery ambient temperature dropped well below 30°C. However this often changed during the day when the macro-environment of the inside of the nursery became excessively hot due to radiation from the sun. We therefore hypothesised that minimising the outside influence of climatic heat on the nursery would enhance effective thermoneutral control and achieve better success rates. It is understood that the use of air-conditioners could artificially cool the nursery wards to counter room warming during the day. This was tried but not considered a sustainable solution as the high frequency of breakdowns without immediate repair or replacement often sent the Unit back to the same ugly situation. Again, this was also noticed to present threats of hypothermia on the other full-term babies in cots as these shared the open nurseries with the incubator babies. It therefore became necessary to find enabling parameters that could be altered to attain the best naturally cooled condition in the nursery. Parameters were preliminarily identified by comparing nursery warming in any two Centres that have direct opposite circumstance. Parameters currently being studied in details were:

1. Siting of the nursery building within hospital complex. Nurseries that were cited as the eastern-most building among the rest in the hospital complex and without any other immediate building east to this seemed to be hotter than those elsewhere cited.
2. Locating nursery within building structure. Nursery apartments that were located on the topmost floor of a multi-storey building seemed hotter than those located on the ground floor.
3. Structural design of nursery outside wall. Nursery designs that provided the main ward at the middle of other flanking rooms, stores or side labs seemed cooler than designs where the wall of the main ward was directly next to the outside. This suggests that some kind of wall lagging designs might provide the needed natural cooling for the macro-environment.
4. Floor to roof height of nursery. Nurseries with higher roofs from the floor level seemed cooler than the shorter ones.
5. Nursery floor level, nursery window height and nursery window blinding material were also identified to seem to create some differences and hence also being studied.

10. Conclusion

This project has been an individual coordinating effort in a drive to lower neonatal mortality rate, restore nursing enthusiasm and patient- carer's confidence in the tropical region of West African state of Nigeria. The project originally set out to find alternative solution to the provision of functional incubators to re-equip the referral hospitals in the country. This began in each of the participated hospital at a time when most of these had no functional incubator. The development and application of the idea of Recycled Incubator Technique (RIT) helped to realise the initial objective as this has made it possible for some of the

hospitals to move from a condition of having no functional incubator to having 15 or more within a short period of time. However, the restoration of proper usage of the incubator to nurse babies exposed the knowledge deficiency of care-providers in incubator application. It was evident that immediate cultural setting and the quality of care with the provided incubator were capable of promoting the spread of diseases among the neonates. Hence, this project extended to the study and proposition of corrective procedures that were easily applicable to the people.

The implementation of the various ideas developed in this study has brought cultural dimension to tweak already established practice facts. This was another way of using the local language to communicate the medicine of neonatal thermocontrol in this tropical region. The methods were easily acceptable and adaptable and seemed to have led to improved outcome among all participating Centres.

Overall, the entire project has achieved significant success across the landscape of Nigeria among all the applying hospitals as published by Amadi et al., 2010. This study was unable to explicitly isolate successes due to the provision of incubators as an initial project and the duo of training courses and modified thermoneutral algorithm as an extended application. These were applied simultaneously. It is commonly acknowledged among hospital administrators in Nigeria that the advent of RIT and the subsequent thermocontrol procedures represented a significant contribution to Nigeria's improving neonatal healthcare delivery (CCEFTHI, 2007). Further investigations are still continuing on how the climate is impacting and militating against overall outcome. We hope to fully define this and proffer solutions on how to ameliorate this and boost survival rate in the region.

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