

UNIVERSITY OF THE WITWATERSRAND
SCHOOL OF CLINICAL MEDICINE
DEPARTMENT OF PAEDIATRICS AND CHILD HEALTH

**MEASURING RADIATION EXPOSURE TO NEWBORNS FROM X-RAYS IN
A DEVELOPING COUNTRY'S NICU**

**DISSERTATION SUBMITTED IN PARTIAL FULLFILMENT OF
REQUIREMENTS FOR A MASTER OF MEDICINE IN PAEDIATRICS AND
CHILD HEALTH (MMED PAEDS)**

CANDIDATE: DR D.M RAKOTSOANE

SUPERVISORS: PROF SAVVAS ANDRONIKOU

DR FIRDOSE, L. NAKWA

Declaration:

I, David Rakotsoane, declare that this research is my own original work. It is being submitted for the degree of Master of Medicine in Paediatrics at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any other degree or examination at this or any other University.

.....

Contributors:

Bronwin Van Wyk

Medical Physicist

MSc

CMJAH and Wits Department of Radiation Sciences; Medical Physics

Abstract:

Background: Radiological studies continue to form part of an important management tool in the Neonatal unit; with advances in technologies extremely premature infants are being ventilated even in resource poor settings with high patient turnover and crowded incubators. At this critical stage of development, a hypothetical question can be asked “Are these vulnerable infants exposed to acceptable levels of radiation?” This study was conducted to measure radiation doses received by these infants from X-rays (primary and scatter beams) in a crowded NICU using Thermoluminescent Dosimeters (TLD).

Methodology: This was a prospective descriptive cross sectional study conducted at Chris Hani Baragwanath Academic Hospital recording doses from X-rays performed over a one month period in 2013 in all neonates admitted to NICU.

Results: The study population comprised of 47 patients, of which 29 (61.7%) were in the very low birth weight (VLBW) and extreme low birth weight (ELBW) category, 8 (17%) low birth weight infants and 10 (21.3%) term infants. The majority of neonates were admitted for Respiratory distress syndrome (54.6%), followed by Meconium aspiration syndrome (14.7%). Congenital pneumonia and surgical conditions made up (31.6%) of the total NICU admissions.

In two months, October and November, 310 X-rays were performed in the NICU. Chest X-rays were the most requested procedure. The mean number of X-rays performed per patient was 8 and the maximum number of X-rays performed on a single patient was 28. Readings from six TLD measuring doses from chest X-ray and abdominal X-rays ranged between 0.005 to 0.08 milliSievert (mSv) per X-ray performed, whilst the reading from three TLD measuring scatter doses ranged between 50 to 150 cm, from the focal point measured 0.0004 mSv per X-ray at 50 and 100cm and zero at 150cm.

Conclusion:

Our study population had on average 8 X-rays during their stay in NICU, with a mean stay of 10 days. The measured doses on some TLDs were comparable to adult doses per X-ray, which is unacceptably high. Combined with scatter doses, patients admitted in beds (1 to 6) and (9 to 12), could have a higher cumulative dose as the distance between the beds was less than 1.5 meters.

Possible reasons for the high doses in this ICU setting could be the parameters used to acquire X-ray, such as focal film distance (FFD), kiloVoltage (kV) showed deviation from the recommended guidelines according to the European Commission Quality criteria for diagnostic radiographic images in pediatrics. This may be related to an absence of local guidelines for radiographic parameters to be used in each weight band. Another reason may be the use of old overhead warmers which were not height adjustable, affecting the focal film distance achievable.

Acknowledgements:

I would like to thank my supervisors Prof S. Andronikou and Dr F. Nakwa for their immense wisdom and patience, without which this study would not have been possible.

I would also like to thank Makhawukani Golele for her support during this process.

Table of Contents:

Table of Contents.....	vii
List of Tables.....	x
List of Figures.....	xi
Abbreviations.....	xii
CHAPTER 1: LITERATURE REVIEW.....	1
1.1 Background.....	1
1.2 How are X-rays produced?	2
1.3 Effects of Ionizing Radiation on Tissue.....	2
1.4 How is radiation doses from X-rays measured?	4
1.5 International Recommendations.....	7
1.6 Study aims and objectives.....	9
CHAPTER 2: METHODOLOGY.....	10
2.1 Study design	10
2.2 Study setting.....	10
2.3 Data collection and interpretation.....	13

2.4 Ethical considerations	14
2.4.1 Ethics approval	14
2.4.2 Confidentiality	15
2.5 Budget	15
2.6 Problems.....	15
CHAPTER 3: RESULTS	16
3.1 Patient profile	16
3.2 Radiological data	18
3.3 Measured doses	19
3.4 Calculated doses.....	21
CHAPTER 4: DISCUSSION.....	23
CONCLUSION	27
RECOMMENDATIONS	28
Appendix 1: Data collection sheet.....	30
Appendix 2: Schematic drawing of CHBAH NICU.....	32
Appendix 3: Consent document.....	33
Appendix4: Ethics approval.....	35

REFERENCES.....	36
-----------------	----

List of Tables:

Table 1: Diagnostic Reference Levels (DRL) of Entrance Surface Dose (converted to milligray (mGy) to the nearest two decimal places). Observed in three European Union paediatric trial.....	8
Table 2: Total number of admission and diagnosis profile.....	16
Table 3: Total number of X-rays performed in NICU.....	18
Table 4: Parameters used in acquiring X-rays.....	19
Table 5: TLD measurements from November.....	20
Table 6: TLD measurements from scatter doses.....	21
Table 7: Examples of doses received per patient.....	22
Table 8: Examples of good radiographic technique: AP projection (newborns).....	24
Table 9: Estimated Doses from diagnostic images in children.....	25
Table 10: Comparison of exposure parameters with other studies.....	26
Table 11: Comparison of scatter doses from AP projections.....	27

List of Figures:

Figure 1: Total number of days in NICU.....	17
---	----

Abbreviations:

- μGy : micro-Gray
- μSv : micro-Sievert
- CHBAH: Chris Hani Baragwanath Hospital
- Cm: centimeter
- CMV: Conventional mode of ventilation
- DAP: Dose area product
- DRL: Diagnostic reference level
- ESD: Entrance skin dose
- FFD: Focal film distance
- HFOV: High frequency oscillating ventilator
- HMD: Hyaline membrane disease
- ICRP: International Commission on Radiological Protection
- kV: kilovolts
- kVp: Peak kiloVoltage
- LBW: low birth weight
- MAP: mean airway pressure
- mSv: milli-Sievert
- mAs: milli-amperes per second
- NEC: Necrotizing enterocolitis
- NICU: Neonatal intensive care unit
- PPHN: Persistent pulmonary hypertension of the newborn
- RTHC: Road to Health Card
- SABS: South African Bureau of Standards
- SD: Standard deviation

- TLD: Thermoluminescent dosimeter
- UAC: Umbilical arterial catheter
- U/S: Ultrasound
- UVL: Umbilical venous catheter
- VLBW: Very low birth weight
- E.M: Electromagnetic
- TAGA: Term born appropriate for gestational age

CHAPTER 1: LITERATURE REVIEW

Background

1.1 Introduction:

The neonatal period is characterized by changes in adapting to extra uterine life as well as the maturation of different organ systems and depending on the gestational age of the neonate, this process can be at a critical part of development. Due to advances in neonatal care, smaller and even smaller preterm neonates are being admitted to the Neonatal Intensive Care Unit (NICU) around the world. The weight criterion for the ventilation of these preterm neonates is constantly changing even in resource-poor developing countries.

Chris Hani Baragwanath Academic Hospital (CHBAH) is located in the Gauteng Province of South Africa and serves the community of Soweto and surrounding townships. In the year 2012 there were 29 134 deliveries in the district surrounding the hospital and 21 588 of those deliveries took place at the hospital. Out of these deliveries 699 were admitted to the Neonatal Intensive Care Unit which has a total of 16 beds. In total 40% of these admissions were those of preterm neonates weighing less 1500g and 28% of weighing between 1500- 2500g (1).

Radiological studies are used in the management of neonates in NICU. X-rays are the most commonly used modality for diagnostic purposes e.g. in Necrotizing Enterocolitis (NEC) and to check for correct placement of invasive lines e.g. Umbilical Venous and Arterial Catheters (UVC and UAC). The inverse square law states that for a point source

and in the absence of attenuation, the intensity of a beam of radiation will decrease as the inverse of the square of the distance from that source (2). With a high patient burden and space limitations in NICU we may be exposing neonates to unacceptable doses of radiation when compared to international standards (3).

1.2 How are X-rays produced?

X-rays are a part of the Electromagnetic Spectrum with a wavelength that can vary between, 10^{-9} to 10^{-13} (m). To produce X-rays in a standard X-ray machine, a cathode (heated metal filament) provides a supply of electrons which are then accelerated through thermionic emission and directed at a metal anode. When these electrons rapidly decelerate upon interaction with the nucleus and there is direct interaction with orbital electrons of the target atom, X-rays are produced (2).

1.3 Effects of Ionizing Radiation on Tissue:

Fundamentally biological effects of ionizing radiation are due to interaction of the radiation with the atoms and molecules in the body, resulting in ionization or excitation of atoms and disruption of molecules within the newborn. If the dose of absorbed radiation is sufficient, it may produce observable effects, the so called somatic effects. Genetic effects are those observed when reproductive cells are involved, these mutated cells are then carried to their descendants. Stochastic effects (latent effects of radiation) are both somatic and heritable (4).

Ionization is defined as the process by which an atom which is electrically neutral (i.e. has equal number of electron and protons) loses an electron. This process can occur as a consequence of X-ray radiation. The original atom is then left slightly different in mass but with a net positive charge (4).

At birth an infant's body contains about 2×10^{12} cells and each cell contains about 10^{14} atoms. Many of these cells perform highly specialized functions in the body. Arrangement of the atoms and molecules in the cells is critical to the development of the cells function e.g. mitosis and meiosis. The probability of inducing structural malformations from X-ray radiation is greatest during the period of major organogenesis, which starts 12 days after conception and extends to about ten weeks post conception (embryonic stage) (4).

If as a result of external factors such as ionizing radiation from X-rays, molecular changes occur within the cell, then these changes can be replicated exactly. In highly specialized cells such damage will occur in the affected cells only. In a developing organism this change may result in trivial or disastrous changes e.g. neoplastic changes (4).

If a mutation occurs in the early stages of development a composite effect is produced. Those cells developing from the mutated cell will be reproduced in the altered form (4).

Somatic effects of ionizing radiation are those evident during the lifetime of the exposed individual. The nature and the severity of these effects are dependent on many factors including:

- The time over which this dose is received i.e. neonatal period;
- The total dose received; and
- The area and part of the body exposed e.g. the testis versus the liver.

The law of Bergioner and Tribondeau states that “the radio-sensitivity of tissue depends upon the number of undifferentiated cells which the tissue contains, the degree of mitotic activity in the tissue and the length of time that the cells of the tissue stay in active proliferation”(5).

1.4 How is radiation doses from X-rays measured?

Radiation dose from an X-ray beam can be affected by;

- The amount of energy in the X-ray beam (milliAmperes, mA).
- The duration that the X-ray is applied (seconds, s).
- The area over which the X-ray beam is applied (centimeter squared, cm²) (6).

Different methods have been employed by different studies (6-10) to measure radiation doses from X-rays in newborn infants with most of these studies measuring radiation experimentally in controlled environments and/or replicated NICU conditions. A variety of instruments have been utilized to measure Entrance Skin Doses (ESD) e.g. Victoreen

model 660 survey meters (9,10,14) and DIADOS diagnostic dose meters (11). Turan et al used tube output measurement in accordance with the following formula (7, 8):

$$ESD (\mu Gy) = (\mu Gy mAs^{-1}) \text{ output} \times mAs \times BSF \times ISL \times (\mu_{en} / \rho)_{air}^{Tis}$$

In this equation ESD is Entrance Skin Dose measured in micro Grey (mGy), mAs is the product of tube current and exposure time, (BSF) background scatter factor was taken as 1.1 at a tube voltage of 50 -70 peak kiloVoltage (kVp) for a neonate with a body thickness of 5cm, ISL is the inverse-square law and mass energy absorption $(\mu_{en} / \rho)_{air}^{Tis}$ coefficient was taken as 1.05 for the range of kVp used. Turan et al conducted their study in Turkey using the aforementioned equation where certain of the variables were calculated i.e. mass absorption coefficient and others were known i.e. tube voltages used to finally calculate the ESD. Another way to measure the ESD is with the use of thermoluminescent dosimeters (TLD). With this method the above equation is not used but instead the TLD measures radiation by being placed in a beam of radiation and later being “heated” the dose of radiation emitted from the crystal within the TLD is thus measured.

Some of the methods or instruments mentioned above would be difficult to use in the proposed study, either due to the technical expertise required to use them or the cost of the different equipment e.g. Victoreen survey meters.

TLD radiation dosimeters are chip like instruments which can contain a variety of crystals e.g. Calcium Fluoride, Lithium Fluoride, Magnesium and Copper. When these materials inside the TLD are exposed to ionizing radiation, electrons are excited from the valence band into the conduction band, where they fall into electron traps which are normally empty in the TLD. This information is then stored almost indefinitely in the chip and only

released when the device is heated, at which time the electrons fall back into luminescence centre in the valence band giving off light. This emitted light is proportional to the exposure of the TLD material (2).

In a study by Turan et al (7), TLDs were used prospectively to measure radiation in 16 infants. The placement of these chips was determined by the clinician and the study does not clearly state which sites were selected for placement of the TLD. This is compared to the study conducted by Armpilia et al (8) which found the most appropriate place to place the TLD chip was on the shoulder and the hip for chest and abdominal X-rays of infants respectively.

Entrance Skin Doses using TLDs (ESD_{TLD}) have been compared to the ones obtained from Tube Outputs (ESD_{TO}) (7), and it has been found that the two methods are well correlated with $R^2 = 0.86$ (Linear regression) (7). In another study, Ampilia et al found a mean ESD_{TLD} of 28.9 ± 0.4 μGy compared with ESD_{TO} of 31.8 ± 2.5 - the result from these two methods again were similar but a reasonable correlation was not found.

Once the ESD is known a variety of calculations can be done to better quantify the risk from the radiation e.g. Dose-area product (DAP) which is the product of ESD and exposed area on the film (cm^2) (11). Absorbed Dose which measures the amount of radiation absorbed per unit mass and the finally the Effective Dose (E) measured in microSievert (μSv) which can be estimated when the following parameters are available for each

radiograph: body weight (g), body thickness (cm), ESD(μ Gy), projection view, tube voltage (kV), half-value layer (mmAl) and exposed film area (cm^2) (10).

1.5 International Recommendations:

The International Commission on Radiological Protection (ICRP) is an advisory body which provides guidance and recommendations regarding protection against ionizing radiation. The ICRP advises that there should be justification for performing imaging that expose patients to ionizing radiation (3):

- That the use of the radiological examination in question will do more good than harm to the patient.
- That the specific radiological examination, when required for a specific disease and age group, has a specified objective and this will usually improve the diagnosis or treatment or will provide necessary information about the exposed individual.
- That the examination is required for that individual patient.

Justification also implies that the necessary results cannot be achieved with other methods that would be associated with lower risk for the patients e.g. chest ultrasound may be used to diagnose effusions or consolidation. The results should be reproducible and have sufficient sensitivity, specificity, predictive value and accuracy with respect to a particular clinical question (3).

The table below shows some of the Diagnostic Reference Levels (DRL), values that have been observed in three European Union paediatric trials (1989/91. 1992. 1997/5) (12).

These include the median, minimum-maximum radiation values and corresponding ratio of minimum to maximum radiation per X-ray examination as well as the part of the body that is being evaluated (Table 1). In paediatrics, these ESDs' have not been formally adopted by the ICRP as the DRL.

Table 1: Diagnostic Reference Levels (DRL) of Entrance Surface Dose (converted to milligray (mGy) to the nearest two decimal places). Observed in three European Union paediatric trial*

Examination Type	Infants Median (mGy)	Min-Max (mGy)	Min:Max (mGy)
Chest AP(1000g newborn)	0.05	0.01-0.34	1:35
Chest PA/AP	0.08	0.02-1.0	1:47
ChestAP (mobile)	0.09	0.03-0.72	1:21
Skull PA/AP	0.93	0.15-4.51	1:30
Pelvis AP	0.26	0.02-1.37	1:76
Full spine PA/AP	0.87	0.12-0.44	1:41
Abdomen AP/PA	0.44	0.08-3.21	1:42

**Table reproduced from ICRP publication 121(3)*

The aim of optimizing radiological protection during an examination is to adjust imaging parameters and institute protective measures in such a way that the required image is

obtained with the lowest possible radiation dose and the net benefit is maximized. This is called the ALARA (as low as reasonably achievable) principle.

1.6 The aim of this study was to determine the radiation exposure from X-rays performed on newborns admitted in NICU at Chris Hani Baragwanath Academic Hospital (CHBAH) and to compare these measurements with international standards (3). The following were the **objectives of the study**:

1. To measure the average radiation doses (mSv) received by neonates during their admission in NICU using Thermoluminescent Dosimeters (TLDs).
2. To measure average scatter and transmission doses (mSv), for patients adjacent to patients having X-ray examinations.

CHAPTER 2: METHODOLOGY

2.1. Study Design:

This study was a prospective descriptive cross sectional study measuring X-ray doses imparted to all neonates admitted to NICU, over a two-month period (October and November 2013).

2.2. Study Setting:

All neonates admitted in the NICU at Chris Hani Baragwanath Academic Hospital during the period, between 1 October and 30 November 2013 (2 months), were eligible candidates for the study. The end point was the discharge of the neonate from the NICU.

Inclusion criteria: All newborn infants admitted to NICU from the beginning of October 2013 until 30 November 2013 who had X-ray examinations were included.

Exclusion criteria: Newborn infants whose parents declined consent to participate in the study and those who did not fit into the pre-defined weight categories were excluded. All patients with unsuccessful TLD measurements (due to technical problems) and all patients undergoing X-rays outside of the study hours were excluded.

One thermoluminescent dosimeters (TLD) was assigned for measuring additive communal dose in each of the following weight categories of patients:

- Band 1: 900 – 1499g Extreme Low Birth Weight (ELBW) and Very Low Birth Weight (VLBW).
- Band 2: 1500 – 2499g Low Birth Weight (LBW).
- Band 3: 2500 – 3500g Term Born Appropriate for Gestational Age (TAGA).

The different weight bands were necessary so as to better estimate the different body widths (thickness) of the infants in centimeters as this was important during the calculation of the Effective Dose and due to the limited number of TLDs available for measurement.

There were also separate TLDs for CXR and AXR in each weight category as well as three additional TLD for measuring scatter at different distances from a patient in each instance.

Whenever a patient was admitted during the study period and underwent an X-ray examination for a clinical indication, the patient data required was accessed from the bed letter and was recorded on the data sheet (Appendix 1). All X-rays performed routinely had radiographic parameters recorded from the individual X-rays i.e. focal film distance, kV, mAs. The body region irradiated during the X-ray examination was noted in the following categories: Chest, Abdomen, Chest and Abdomen. Only radiations from X-rays conducted during regular working hours (08:00am -16:00pm) were recorded, as the primary investigator was responsible for the safe keeping of the TLDs. These were on loan from the University of the Witwatersrand Medical Physics Department. Calibration and reading of the TLD doses was performed by the South Africa Bureau of Standards (SABS).

The calibration of TLDs includes irradiation using a Cs-137 beam which is housed in the Metrology laboratory. They were irradiated with a beam dose ranging from 425 mR (MilliRoentgen), 600 mR and 3100 mR. TLDs were processed after 24 hours of irradiation for fading purpose. The measurements are traceable to the National Metrology Institute of South Africa (NMISA) standards because a 1000 cc chamber is sent to NMISA for calibration and when it comes back it is used to validate our beam output measurements. The system sets up the date for the next calibration for each TLD.

Before each X-ray was performed the primary investigator selected the TLD designated to that weight band and placed it either above the patients right shoulder for a Chest X-ray (CXR), on the right hip for Abdominal X-rays (AXR) and on the right hip for combined Chest and Abdominal X-rays (8). AXR and combined CXR/AXR used the same TLD.

The three additional TLDs were used in each instance to measure the scattered dose (AP projections only). These were placed at intervals of 50cm from the patient and 50cm from each other up to 150cm. This was planned so that 150cm was the maximum distance from the isocenter, as a previous study showed the maximum scatter dose is at one meter (14). These were not used when a cross table / horizontal beam radiograph was performed.

Each weight category had two TLDs one was assigned for CXR and the other for AXR. In total we used nine TLDs: six for measuring primary radiation from CXR/AXR (one for each weight band for CXR and one for each weight band for AXR and CXR/AXR combination) and three for scatter doses.

All admissions to NICU during the study period were noted and the total number of X-rays performed during that period was also calculated.

The (Shimadzu Mobile Art Evolution) portable X-ray machine was used during the entire study to produce X-rays. Carestream Directview Vita CR was used in the processing of the X-ray plate and the Kodak DryView for printing of the X-ray films.

2.3 Data Collection and Interpretation:

The cumulative TLD dose measurement, for all radiographs in each of the three weight bands was determined in mSv (which is equivalent to mGy). The total cumulative dose was then divided by the number of radiographs contributing to that TLD reading during the study period (dose per radiograph). This average dose was then multiplied by the number of X-rays performed on each patient (dose per patient).

Cumulative scatter doses were calculated in the same manner for the 3 distances from the source and then divided by the number of radiographs that contributed to the total reading of the TLD.

Data was entered into REDcap (16) which is an online data managing tool and thereafter imported into Statistica version 11(Statsoft, USA). All categorical data is reported as numbers and percentages with continuous variables reported as means (standard deviations) or medians (inter quartile ranges) depending on the distribution of data. Categorical data were analyzed by using frequencies as well as proportions and further reproduced using histograms together with tables. Continuous data was analyzed using standard deviation and means and further reproduced using summaries and pie charts.

2.4. Ethical considerations

2.4.1 Ethics approval:

Ethics approval was granted by the University of the Witwatersrand Ethics Committee (HREC) clearance number M130948 (Appendix4). Consent from parents was taken before the patient was enrolled in the study (Appendix3).

2.4.2 Confidentiality:

Confidentiality of the patient information from the files was strictly maintained. No identifiers (i.e. patient name or hospital number) were reflected on the data sheet. Identifiable data was coded and the 'links' were kept separate. The data sheets only contained a study number (code) which allowed for the matching of a data sheet to a particular patient.

2.5 Budget:

The cost involved in the study was for stationery, printing, photocopying and binding. This cost was borne by the primary investigator as there was no external funding for this study.

2.6 Problems:

The radiographers were required to note the parameters required for the study on the X-rays as well as the total number of X-rays. Incorrect data capture may have occurred in this regard.

TLD measurements from the month of October were incorrectly processed and thus the doses from that month are not presented in this paper. This was explained by SABS as partly a human error in the processing of the TLD chips.

CHAPTER 3: RESULTS

From the month of October to November 2013 a total of 118 patients were included in the study on admission to NICU. A total of 71 neonates were excluded, either due to consent not being granted, admission and/ or discharge outside the study times i.e. the weekend, or being admitted to the Surgical NICU division which hosts 6 beds and patients who passed away within the first 24 hours of admission. This left a study population of 47 patients for the radiation evaluation component of the study.

3.1 Patient Profile:

There were a total of 118 patients admitted into the NICU over the two month period. Respiratory distress syndrome was the commonest admission diagnosis followed by surgical conditions e.g. NEC (Table 2). Diagnosis under other includes e.g. septic shock, apneas etc.

Table 2: Illustrates total number of admissions and breakdown of diagnosis profile

MONTH	OCTOBER TOTAL ADMISSIONS =51 n (%)	NOVEMBER TOTAL ADMISSIONS=67 n (%)	Total = 118 n (%)
Respiratory distress syndrome (RDS)	17 (33)	22 (33)	39 (33)
Meconium aspiration syndrome	3(6)	9 (13)	12 (10)
Congenital Pneumonia	3 (6)	5 (7)	8 (7)
Surgical	14 (27)	12 (18)	26 (22)
Other	14 (27)	19 (28)	33 (28)

Of the study population of 47 patients, 29 (61.7%) fell into Band 1 (VLBW and ELBW), 8 (17%) fell into Band 2 (LBW) and 10 (21.3%) fell into Band 3 (Term).

The mean length of stay in the study population of 47 patients was 11 days; the range was between 1 day to 55 days (Fig 1).

Total (N)	Missing	Unique	Min	Max	Mean	StDev	Percentile						
							.05	.10	.25	.50 Median	.75	.90	.95
47	0 (0%)	21	1.00	55.00	10.64	10.24	2.00	2.00	4.00	7.00	13.50	25.80	28.00

Lowest values: 1, 2, 2, 2, 2

Highest values: 27, 28, 28, 33, 55

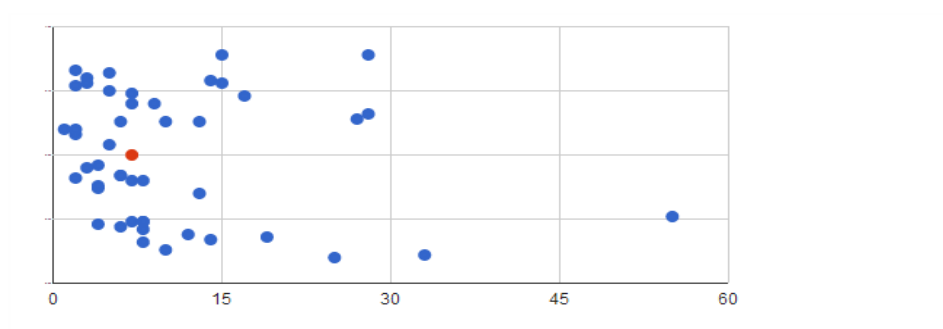


Figure 1: Total number of days in ICU (Horizontal axis: Days)

Three patients (6.4%) enrolled in the study received nasal continuous positive airway pressure (NCPAP), with majority of the patients 44 (93.6%) being put on a conventional mode of ventilation (CMV). High frequency oscillation ventilation (HFOV) was used in 9 patients (19.1%) as a step up to the CMV, i.e. when patients were difficult to ventilate. No patients were admitted on nasal cannula (NC).

3.2 Radiological Data

There were a total of 310 X-rays performed in the NICU during the two month study period (127 in October and 183 in November) for the 118 patients. The most frequently requested X-ray type were CXR 238 (77%) over the two-month period (Table 3).

Table 3: Total number of X-ray performed in the NICU.

Month	Total number of X-rays	CXR n (%)	AXR n (%)	AXR/CXR n (%)
October	127	100 (79)	19 (15)	8 (6)
November	183	138 (75)	24 (13)	21 (12)
Total	310	238 (77)	43 (14)	29 (9)

From the study population (n=47), the mean number of X-rays performed was 8 (± 7.57 SD). Two patients (4.2%) had only one X-ray while the maximum number of X-rays performed was 28 over a two month period.

Twenty six patients (55.3%) had their doses analyzed as these, patients had successful TLD measurements. These patients had a total of 60 radiographs in the month of November.

The mean FFD used was 89.6cm, with a mean kV and mAs of 43.38 and 1.76 respectively for the 26 patients (Table 4). These parameters were measured prospectively at the time the X-rays were being performed as this data is not recorded on the X-ray film or log book.

Table 4: Parameters used in acquiring X-rays represented in Min/Max/Mean values: n = 26

Parameter	Minimum	Maximum	Mean	Standard Deviation
FFD (cm)	70	105	89.46	8.23
kV	42	48	43.38	1.37
mAs	1.40	2.5	1.76	0.20
Area exposed (cm²)	72	221	117	42.26

3.3 Measured Doses

The TLD assigned to Band 1 was exposed to the most number of X-rays totaling 22 (CXR). The reading was 0.41mSv with an average of 0.02 mSv per X-ray film. The highest measurement was in the TLD used for CXRs in weight Band 2 – with a total number of X-rays of 8 with a reading of 0.62 mSv and an average of 0.08 mSv per radiograph.

Table 5: Thermoluminescent Dosimeter (TLD) Reading in November for n=60 X-rays.

TLD NO.	Weight Band	Type of X-ray	Number of X-rays	Total TLD Reading (mSv)	Average dose per X-ray (mSv)
404864	1	CXR	22	0.41	0.02
421190	1	AXR	10	0.31	0.031
49738	2	CXR	8	0.62	0.08
205503	2	AXR	2	0.01	0.005
11035	3	CXR	16	0.48	0.03
421186	3	AXR	2	0.01	0.005

Three TLD badges were used to measure scattered radiation from 23 AP projections of the total 60 radiographs. At 50cm the reading was 0.01mSv with an average of 0.0004mSv per radiograph and at 100cm the reading was the same as for a TLD placed 50cm from the patient. The TLD placed at 150cm registered no reading (Table 6).

Table 6: TLD badges measuring scatter doses from AP projections

TLD No:	Distance (cm)	No. Of X- rays	Total TLD Reading (mSv)	Average dose per X-ray (mSv)
214929	50	23	0.01	0.0004
422799	100	23	0.01	0.0004
405308	150	23	0	0

3.4 Calculated Doses

In table 7 below are examples of different estimated doses received per patient in each weight category based on the different TLD readings per X-ray. These are estimated doses derived from the average TLD readings. Patient 043 in weight band 1 was admitted for 15 days and had 4 X-ray examinations (CXR). The average TLD reading for this weight band was 0.02mSv and multiplied by 4 X-rays received, the patient's cumulative dose is calculated to be 0.08mSv ($0.02\text{mSv} \times 4$). Assuming this patient was in Bed 2 (see Appendix 2) and each of the surrounding patients were X-rayed daily ($n=30$ X-rays) the patient would have been exposed to 0.012 mSv ($30 \times 0.0004\text{mSv}$) from the scatter radiation (TLD at 100cm read 0.0004mSv), giving this patient a total of 0.092 mSv during their admission to NICU. Other patients would have had significantly higher doses if the example above was used in each of the different weight bands (Table 7).

Table 7: Examples of doses received per patient in different weight bands according to averaged TLD doses.

Weight band	TLD	Study number	Days in ICU	CXR(n)	AXR(n)	FFD (average)	kV (average)	mA s	Cummulative Dose (mSv)
1	404864/ 421190	043	15	4	0	83	44	1.7	0.08
2	49738/2 05503	038	4	3	0	96	43	1.8	0.21
3	11035/1 186	029	28	10	2	88	43	1.7	0.31

CHAPTER 4: DISCUSSION

The European Commission paper on quality criteria for diagnostic radiographic images represents a guide to the different parameters needed firstly to reduce radiation exposure to newborn infants, secondly to attain the highest quality of X-rays i.e. Table 8 (13). While the recommended value for FFD is 80 – 100cm, our study FFD results recorded values as low as 70cm. The FFD is influenced by the height of the radiographer and in our study also apparently by the make of the radiant warmer used - some warmers were older models and were not height adjustable. The mean FFD in our study was 89cm which falls well within the recommendation. However radiographic voltage in our study (range 42-48 kV), fell well below the recommended range of 60-65kV. One of the reasons for this may be that junior staff are performing X-rays in NICU, without clearly identifiable protocols for choosing X-ray parameters, including kilovolt settings. The exposure times in our patients were kept below 4s as per recommendations. Overall the parameters used in acquiring X-rays in this study did not match those of international recommendations. Other measures such as the use of lead rubber masking were not used when X-rays were performed in NICU. The physical limitations of this environment and the lack of equipment, could account for this.

Table 8: Examples of good radiographic technique: AP projection (newborns).

Patient position:	Supine
Radiographic device:	Bedside(table)
Nominal focal spot value	0.6 (≤ 1.3)
Additional filtration	Up to 1mm Al + 0.1 or 0.2mm Cu
Anti-scatter grid	None
Screen film system	Nominal speed class 200 – 400
FFD	80 – 100 (150)cm
Radiographic voltage	60 – 65 kV
Automatic exposure control	None
Exposure time	< 4 ms
Protective shielding	Lead-rubber masking of the abdomen in the immediate proximity of the beam edge; if direct placement not possible, then masking on the incubator lid.

Some patients were exposed to doses as low as 0.08 mSv per stay in NICU which when compared to figures given by the Imagegently campaign would constitute about one day's worth of background radiation (Table 9). However, other patients may be exposed to doses as high as 1 to 2 mSv per admission in NICU, which is equivalent to 8 months of background radiation. The reason for these variations in doses are to a large degree because of the higher number of X-rays some babies receive due to their illnesses e.g.

patients with NEC would get serial X-rays looking for perforations. Other reasons however, can include use of incorrect imaging parameters such as FFD and kV and poorly serviced portable X-ray machines that can leak radiation and therefore imparting higher doses despite the use of appropriate / recommended parameters.

Table 9: Estimated Doses from Diagnostic imaging in Children
(www.imagegently.org)

Source	Estimated Dose	Equivalent to Background
Natural background	3mSv/year	
Chest X-ray (single view)	0.01-0.15 mSv	1 day of background
Chest X-ray (double view)	0.1-0.15 mSv	
Head CT (adjusted)	Up to 2 mSv	8 months of background/About 100 chest x-rays

In comparison to similar studies conducted in Turkey by Turan et al (7), the Entrance Doses (ED) of this study were significantly higher for CXR 30 μ Sv verses 15 μ Sv. Table 10 summarizes the exposure parameters and radiation doses in 3 other studies and compares against the findings of the current study.

Table 10: Comparison of exposure parameters with other studies:

Reference	Exam	Mean voltage (kV) Range[]	Mean (mAs)	Mean mSv per radiograph	ESD (μGy) per Radiograph	ED (μSv) per Radiograph
This work	CXR	43	1.8	0.03		30
	AXR	43	1.7	0.02		20
Armpilia et al (8)	CXR	53	2.0		36	7.8
	AXR	53	2.0		39	10.2
Turan et al (7)	CXR	49	1.9		67	15
	AXR	48	2.0		65	22
Brindhaban et al. (9)	CXR	73-52			74	18
	AXR	73-50			146	42

The scatter radiation measured during the study was significantly higher than the work of Burrage et al. (Table 11). The possible reasons for this could be due to the use of lower

FFD. The spatial arrangement in NICU should be attended to as significant doses have been shown in distances less than 1.5 meters (14) and overcrowded facilities in our institution results in shorter distance between the beds than other departments in developed countries.

Table 11: Comparison of Scatter doses from AP projections (project)

Reference	Exam	Project	kV	mA	FF	Dose (mSv) 50cm	Dose (mSv) 100cm	Dose (mSv) 150cm
This work	CXR/ AXR	AP	43	1.8	89	0.0004	0.0004	0
John W. Burrage et al (14)	CXR/ AXR	AP	52	3.2	100	0.000051	0.000011	

Conclusion:

This study measured radiation dose exposures to newborns at Chris Hani Baragwanath Academic Hospital (CHBAH) and found them unacceptably high in comparison to published literature. In addition the scatter doses were higher than those published.

X-ray examinations remain an important tool for diagnostic purposes and monitoring in NICU, more so in developing countries where ultrasound investigations are still not readily available. This study showed that the parameters used in acquiring X-rays were different from published guidelines both with regard to the Focal Film Distance and with regard to the kV. Especially in settings where trainees and inexperienced radiographers are called on to perform clinical duties in the intensive care unit, there is a role for clearly visible and defined protocols to assist the radiographer when performing X-rays. Clinicians also need to be aware of the dangers of radiation including those of scatter radiation in the crowded settings of a developing country intensive care unit, and where possible they should minimize the number of X-rays requested. Justification for X-ray examination should be done in every case following the ALARA principles.

Recommendations:

Further studies are required to quantify the number of X-rays to which infants are exposed to throughout their stay in the Neonatal Unit, as NICU is a small part of the unit as a whole. A radiation card where all X-rays performed during the admission period can be recorded is a way of alerting clinicians to the number of radiographs performed. This information can then be transferred to Road To Health Card/Booklet. Regular audit of radiograph numbers should be performed in units where PACS (patient archive and communication systems) is available.

Written protocols for X-ray settings are needed in NICU, to be used by radiographers when performing X-ray studies on preterm infants in different weight categories, so as to not have a 'one size fits all' approach. Senior staff members need to be assigned to the NICU to train and educate junior staff members.

All medical staff working in neonatal units should be made aware of the possible radiation exposure to infants from X-rays, and possible ways to limit the number of X-rays requested on these infants i.e. clear indication on why the X-ray is needed. X-ray investigations can be combined i.e. to check lines with those that are required to look for pathology.

Patients should ideally be kept more than 1.5 meters apart, to avoid unnecessary radiation from scatter.

Appendix 1:

Data Collection Sheet:

Measuring Radiation Exposure

Study Code: _____

Patients Demographics:

DOB: ____/____/____ Birth Weight: _____

Gender: M/F Gestational Age: _____

Weight Band: _____

Band1: 900 – 1499g

Band2: 1500 – 2499g

Band3: 2500 – 4500g

ICU Data:

Date of Admission: ____/____/____

ICU Bed Number: _____

Date of Discharge: ____/____/____

Total Days in ICU: _____ Reason for ICU admission: 1_____

Radiographs:

TLD No: _____

Total Number of X-rays for this weight band: _____

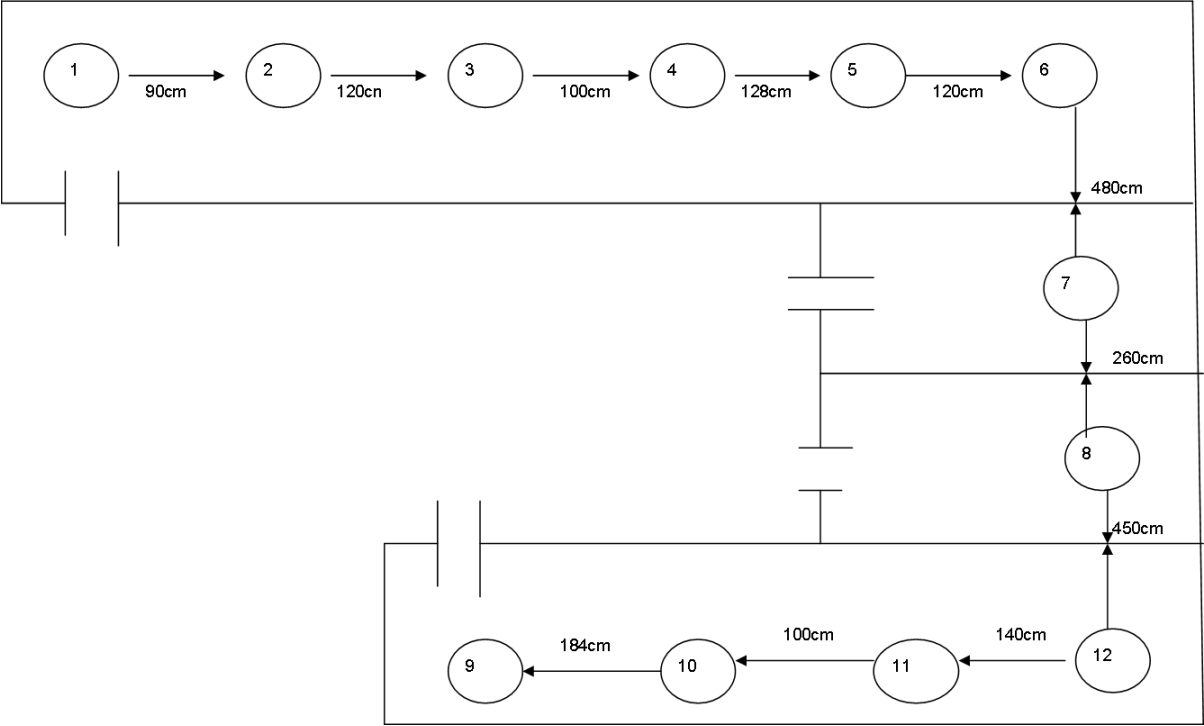
TLD Reading for this weight band: _____

X-rays:

	Type of X-ray	Reason for X-ray	Focal Distance	Film	kV	mAs
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Appendix 2:

Schematic Drawing of CHBAH NICU (not to scale):



Appendix 3:

INFORMATION DOCUMENT:

Measuring Radiation Exposure to Newborns from X-rays in a Developing Country's NICU

Dumelang, Sanibona, Greetings.

Introduction:

My name is Dr David Rakotsoane. I work in the Neonatal Unit. I am doing research your baby to measure how much radiation from X-rays the baby is exposed to whilst they are admitted to the NICU. Research is just a process to learn the answer to a question. We will only be measuring the radiation from X-rays which are done routinely in the care of your baby.

Invitation to participate:

I am kindly asking your permission to have me include your child in the research study. Participation is voluntary. You are not forced to participate or give consent. If you do refuse the baby's treatment and care will not be affected or altered in any way or form. You have the right to withdraw from the study at any time even after you have initially agreed to participate.

What is involved in the study?

The study will take place between the months of October and November 2013. Once I have your permission to include your child in the study. The baby will be given a unique number so that their information remains confidential. However, personal information may

be released if it is required by law. Organizations that may inspect and/or copy your research records for quality assurance and data analysis include groups such as the Research Ethics Committee and the Medicines Control Council(where appropriate). If results are published, this may lead to individual/cohort identification.

A small machine called a Thermolumiscent Dosimeter (TLD)*, will be placed next to your baby every time they have X-rays taken. This machine (TLD) then measures the radiation your baby receives from the X-rays. The TLD machine will not cause harm to your baby. Your child will be included in the study from the day they are admitted to NICU until they are discharged from NICU.

Risks:

There is no risk to your child from our study, as we are merely observing/measuring with a machine which will be placed next to the child.

Benefits:

The benefits will be that we will gather information on the radiation doses that babies are exposed to and this can be used to change the policy in the unit on how we request or deliver X-rays and radiation respectively.

The participant will be given pertinent information on the study while involved in the project and after the results are available.

Confidentiality:

Efforts will be made to keep personal information confidential. Absolute confidentiality cannot be guaranteed. Personal information may be disclosed if required by law.

Contact details of researcher/s – for further information.
Dr D.M Rakotsoane

Appendix 4:



R14/49 Dr David Mahumapelo Rakotsoane

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M130948

NAME: Dr David Mahumapelo Rakotsoane
(Principal Investigator)

DEPARTMENT: Paediatrics
Chris Hani Baragwanath Academic Hospital

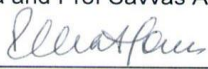
PROJECT TITLE: Measuring Radiation Exposure to Newborns in a
Developing World's NICU

DATE CONSIDERED: 27/09/2013

DECISION: Approved unconditionally

CONDITIONS:

SUPERVISOR: Dr Firdose Nakwa and Prof Savvas Andronikou

APPROVED BY: 
Professor PE Cleaton-Jones, Chairperson, HREC (Medical)

DATE OF APPROVAL: 25/10/2013

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Secretary in Room 10004, 10th floor, Senate House, University.
I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report.**

Principal Investigator Signature _____

Date _____

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

References:

1. Nakwa, F. 2012, Chris Hani Baragwanath Neonatal ICU Stats, Johannesburg (Personal communication Dr Nakwa).
2. Dendy P, Heaton B. Production of X-rays. In: Webster J, Tabakov S, Kwan-Hoong N, editors. PHYSICS FOR DIAGNOSTIC RADIOLOGY. Third ed. 6000 Broken Sound Parkway NW: Taylor and Francis Group; 2012. p. 23-112.
3. ICRP 2013, Radiological Protection in Paediatric Diagnostic and Interventional Radiology. ICRP Publication 121. Ann ICRP 42(2), PP 24 – 30. <http://www.icrp.org/publication.asp?id=ICRP Publication 121> (accessed 4/6/2013)
4. Rees, D. 1967, "matter and radiation" in Principles of Radiation Protection, 1st Edn, Butterworth, London, pp. 25 -26.
5. Pizzarello D, Witcofski R. Basic Radiation Biology. Second ed. Philadelphia: Lea and Fehiger; 1975.
6. Cheng-Chung, Y. 2010, "Radiation Safety in the Neonatal Intensive Care Unit: Too Little or Too Much Concern?", *Full*, vol. 51, no. 6, pp. 313-315.

7. Turan, Olga. - Dogan, Bor. et al 2008, "Radiation Exposure to Premature Infants in a Neonatal Intensive Care Unit in Turkey", vol. 9, no. October, pp. 416-417.
8. Armpilia, C I. Fife, A J. Croasdale P L. 2002, "Radiation dose quantities and risk in neonates in a special care baby unit", *The British Journal of Radiology*, vol. 75, no. July, pp. 590-595.
9. Brindhaban, A.-, C U. 2006, "Estimation of Radiation Dose during Diagnostic X-ray Examination of Newborn Babies and 1-Year-Old Infants", *Medical Principles and Practice*, vol. 15, pp. 260-265.
10. Wilson-Costello, Deanne.-Rao,Pejavar.-Morrison,Stuart.-Hack,Maureen. 1996, "Radiation Exposure from Diagnostic Radiographs in Extremely Low Birth Weight Infants", *Pediatrics*, vol. 97, no. 3, pp. 369-374.
11. Kathrin, Puch-Kapst. Ralf, Juran. Brigitte, Stoever.- Roland, R. Wauer. 2009, "Radiation Exposure in 212 Very Low and Extremely Low Birth Weight Infants", *Pediatrics*, vol. 124, no. 6, pp. 1556-1564.

12. European Commission, 1999. Guidance on Diagnostic Reference Levels (DRLs) for Medical Exposure. European Commission Publications, Radiation Protection 109, Brussels: https://ec.europa.eu/energy/sites/ener/files/documents/109_en.pdf (accessed: 28/10/2013)
13. South African Bureau of Standards 2012, Obtaining Element Correction Factors (ECFs), Document No.725 WI 108, SABS, Pretoria.
14. Burrage, John. Rampant, Peter. Beeson, Brendan. 2003, "Scatter and Transmission doses from Several Pediatric X-ray examination in a nursery", *Pediatric Radiology*, vol. 33, pp. 704-708.
15. Radiology society of South Africa/ South African Society of Paediatric Imaging, Paediatric imaging guidelines version 1.1 10/01/2013 , <http://rssa.co.za/clinical-guidelines-and-protocols/blog.html> (accessed 10/7/2013)
16. Paul A. Harris, Robert Taylor, Robert Thielke, Jonathon Payne, Nathaniel Gonzalez, Jose G. Conde, Research electronic data capture (Redcap) - A metadata-driven methodology and workflow process for providing translational research informatics support, *J Biomed Inform.* 2009 Apr; 42 (2):377-81.