SENRA Academic Publishers, Burnaby, British Columbia
Vol. 2, No. 1, pp. 309-315, 2008
ISSN: 1715-9997

Canadian Journal of pure&applied sciences

MEASUREMENT OF RADIATION DOSES TO YOUNG INFANTS FROM DIFFERENT SIDES AND DIFFERENT DISTANCES OF PARENTS UNDERGOING NUCLEAR MEDICINE INVESTIGATIONS

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ABSTRACT

This study was conducted in order to calculate the radiation exposure that infants may anticipate receiving from a parent who has recently had a nuclear medicine procedure. Radiation dose rate (μSv/24hr) was measured in 34 patients (by a digital survey meter) for four commonly performed nuclear medicine procedures (bone, liver/spleen, renal and thyroid) at the skin surface, 10, 30, 60, 100 and at 150 cm from the patient, within 3 and 1 hr (3 hrs for bone scan patients and 1 hr for the other three procedures) postinjection. The measurements were performed also for different sides of the patients (anterior, posterior, left and right). For bone scans, a normal injected dose of technetium-99m-MDP (^{99m}Tc-MDP) resulted in a radiation exposure (from posterior side of the patient) 0f (760 ± 162) μSv/24hr at the skin surface, (431 ± 107) μSv/24hr at 10 cm, (197 ± 40) μSv/24hr at 30 cm, 84 ± 20 at 60 cm, (40 ± 07) μSv/24hr at 100 cm and (22 ± 7) μSv/24hr at 150 cm. Also for the bone, the radiation dose rate measurements obtained (from left side of the patient) were (563± 117) μSv/24hr at the skin surface, (349 ± 83) μSv/24hr at 10 cm, (139 ± 30) μSv/24hr at 30 cm, (59 ± 1) μSv/24hr at 60 cm, (31 ± 9) μSv/24hr at 100 cm and (15 ± 4) μSv/24hr at 150 m. We found that the variations in percentage (%) between posterior and left side mean measurements were 25.9, 19.0, 29.4, 29.8, 22.5 and 31.8 % at the skin, 10, 30, 60, 100 and 150 cm respectively. When we search for a “conservative” values and concepts, concerning the radiation safety related to the radioactive patient, we believe that anterior and posterior sides values must be taken into account, especially for the cases that required measurements taken from positions in close proximity of the patient. Public personnel must be educated in nuclear medicine procedures to minimize exposure to their relatives (infants).

Keywords: Radiation protection, nuclear medicine, young infants and radiation dose rate.

INTRODUCTION

Exposure to ionizing radiation predominantly results from two sources: (1) natural or background radiation, and (2) medical radiation. Nuclear medicine examinations performed annually in the world have progressively increased in number and represent a significant proportion of the total medical radiation exposure (Michael, 1990). Critical groups outside a hospital (relatives, infants and children) are concerned about the exposure that they may receive from radioactive patients. Once a radio-pharmaceutical has been administered, the radiation emitted from the patient acts as a potential mobile source of exposure to other individuals.

The variation of radiation dose rate with distance from a patient will depend on the anatomical distribution of the radioactivity and hence on the radiopharmaceutical administered (Mountford, 1997). For ^{99m}Tc-nanocolloid or tin colloid where the radioactivity is confined largely to the liver, spleen and the bone marrow of the axial skeleton, the decrease of dose rate with distance from the patient was found to be greater than for ^{99m}Tc-phosphonate where the radioactivity is distributed over a greater area of the body (i.e. more or less uniformly throughout the entire skeleton) (Mountford *et al.*, 1991 and Mountford *et al.*, 1996). These extrapolations and interpolation will be made easier if the variation of dose rate with distance can be described by a simple mathematical function.Thermoluminescence dosimeter (TLD) measurements and Monte Carlo calculations have shown that beyond a given distance, which increases with the area of the source, the inverse square law can be used to describe the variation of dose rate with distance.

Contact with radioactive tissue from the patient or exposure to radiation emitted from radioactivity retained by the patient presents a risk to hospital staff and to members of the public. In the later group, members of the patient’s family, particularly young children and breast-fed infants, are of particular concern, and their associated risks require careful assessment.

Very little exists in the radiologic or nuclear medicine literature concerning the measurements of the radiation exposure, from different sides of the parent, to infants who may be in close proximity to parents, who have recently received radionuclides for diagnostic scan. Therefore, it was decided to measure the radiation doses

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Table 1. Variation in dose rate (%) to young infants, that measured from different sides and different distances from parents undergoing nuclear medicine investigations.
Variation in dose rate (%) for different sides

	Procedure	Agent	Sides	Skin	10 cm	30 cm	60 cm	1 m	1.5 m
Bone	^{99m}Tc-MDP	1*	25.9	19.0	29.4	29.8	22.5	31.8	26.4**
Liver/	^{99m}Tc-TC	2*	76.3	70.6	60.8	69.0	60.0	62.5	66.5**
Spleen Renal	^{99m}Tc-DTPA	3*	13.4	17.6	18.8	32.5	30.9	10.3	20.6**
Thyroid	^{99m}Tc-Free	4*	49.2	59.5	46.2	41.7	48.1	54.5	49.9**

1* = ((Posterior dose rate – Left dose rate)/(Posterior dose rate))x100%
2* = ((Anterior dose rate – Left dose rate)/(Anterior dose rate))x100%
3* = ((Anterior dose rate – Posterior dose rate)/(Anterior dose rate))x100%
4* = ((Anterior dose rate – Posterior dose rate)/(Anterior dose rate))x100%

**Average value of the variation in dose rate for the readings obtained from different distances (from skin to 1.5 m).

that infants may be exposed from various distances and sides of their parents who were injected for four commonly performed type of routine diagnostic radionuclide procedures.

MATERIALS AND METHODS

Radiation dose rate (μSv/hr) was measured (by a digital survey meter, Morgan Model # 3100, Dosimeter Corporation, 160 Bear Hill Road, Waltham, MA 02154) for 34 patients through four commonly performed nuclear medicine procedures (bone, liver/spleen, renal and thyroid) at the skin surface, 10, 30, 60, 100 and at 150 cm from the patient, within 3 and 1 hr (3 hrs for bone scan patients and 1 hr for the other three procedures)), after radiopharmaceutical administration. The patient's weight, height, the radiopharmaceutical, the dose administered, and the time postinjection of the measurements were recorded. The types of procedures and radio-pharmaceutical studies are listed in Table 1. The results were calculated and reported as the mean of the results for each procedure. The critical group will be the infants young enough to be held for prolonged periods in close contact with the parents regardless of the sex of the parent, and if the parent is a mother, regardless of whether or not she is breast feeding. Doses to young infants in these circumstances have been estimated by multiplying the dose rate measured on and near the surface of the patient (parent) by an effective exposure time (T_{eff}) which accounts for the intermittency of close contact and for dose rate decay (Mountford, 1985). T_{eff} is calculated by assuming that the duration θ of each exposure and the time t between each exposure remain constant:

$$T_{eff} = [1\text{-exp. }(-\lambda.\ \theta)]/\ \lambda[1\text{-exp}(-\lambda.t)]$$

Where λ is the dose rate decay constant. Values of T_{eff} are given in Table 7 (Mountford *et al*., 1991), corresponding to the maximum time of 9 hrs in every 24 hr period which has been reported to be spent by an infant in close contact with a parent. The value of T_{eff} applied in this research is equal to 3.9 hours . This value is assumed to be the same for the all compounds of ^{99m}Tc (Rose *et al*., 1990).

RESULTS

Results concerning the infants dose rates that measured from different sides and distances of the parents, for the four procedures are shown on Figures 1 to 4. For bone scans, a normal injected dose of technetium-99m-MDP (^{99m}Tc-MDP) resulted in a radiation exposure (from posterior side of the patient) 0f (760 ± 162) μSv/24hr at the skin surface, (431 ± 107) μSv/24hr at 10 cm, (197 ± 40) μSv/24hr at 30 cm, (84 ± 20) μSv/24hr at 60 cm, (40 ± 7) μSv/24hr at 100 cm and (22 ± 7) μSv/24hr at 150 cm. Also for the bone, the radiation dose rate measurements obtained (from left side of the patient) were (563 ± 117) μSv/24hr at the skin surface, (349 ± 8.3) μSv/24hr at 10 cm, (139 ± 30) μSv/24hr at 30 cm, (59 ± 1) μSv/24hr at 60 cm, (31 ± 9) μSv/24hr at 100 cm and (15 ± 4) μSv/24hr at 150 cm. A recommended dose of ^{99m}Tc-Sulfur collide was injected for liver/spleen scans resulting in radiation dose (from anterior side of the patient) of (1459 ± 592) μSv/24hr at the skin surface, (647 ± 167) μSv/24hr at 10 cm, (176 ± 27) μSv/24hr at 30 cm, (71 ± 10) μSv/24hr at 60 cm, (30 ± 10) μSv/24hr at 100 cm and (16 ± 5) μSv/24hr at 150 cm. Most liver/spleen scan patients did not void prior to the measurement.

For the bone scan, we found that the variations in percentage (%) between posterior and left side mean measurements [((left side dose - posterior dose)/(left dose)) x 100%] were 25.9, 19.0, 29.4, 29.8, 22.5 and 31.8 (with average of 26.4%) at the skin, 10 cm, 30cm, 60cm, 100 cm and 150 cm respectively. The variations in measurements for liver/spleen scan between anterior and posterior positions measurements were 76.3, 70.6, 60.8, 69.0, 60.0 and 62.5 % (with average of 66.5%) at the skin, 10, 30, 60, 100 and 150 cm respectively. Variation in dose rate (%) to young infants, that measured from different sides and different distances from parents undergoing nuclear medicine investigations are shown in Table 1.

DISCUSSION

From Figures 1 to 4, we observed that the variation in doses to young infants that measured from different sides of the patients (parents) is obvious (large), for the distance less than 100 cm from the parent, whereas for the distances greater than 100 cm the doses become nearly the same (variation is very small) for all positions. The maximum dose rate on Figure 1 was registered from the posterior position for bone scan, whereas the maximum dose for the other scans (liver/spleen, renal and thyroid) were registered from the anterior position as shown on figures 2 to 4.

Table 1 demonstrates the variation in dose rates (in %) between different sides for the same organ. For example, the variation in doses between posterior and left positions [(posterior side dose – anterior side dose)/(posterior side dose) x 100%] at the skin for the bone is equal to 25.9%, with the average variation of 26.4% for the different distances (skin, 10, 30, 60, 100 and 150 cm) from the patient. From Table 1, we noticed also that the highest variation in dose rate was appeared in liver/spleen scan between anterior and left positions (with average equals to 66.5%), whereas the minimum difference was appeared in renal scan between anterior and posterior positions (with average equals to 20.6%).

Figure 1

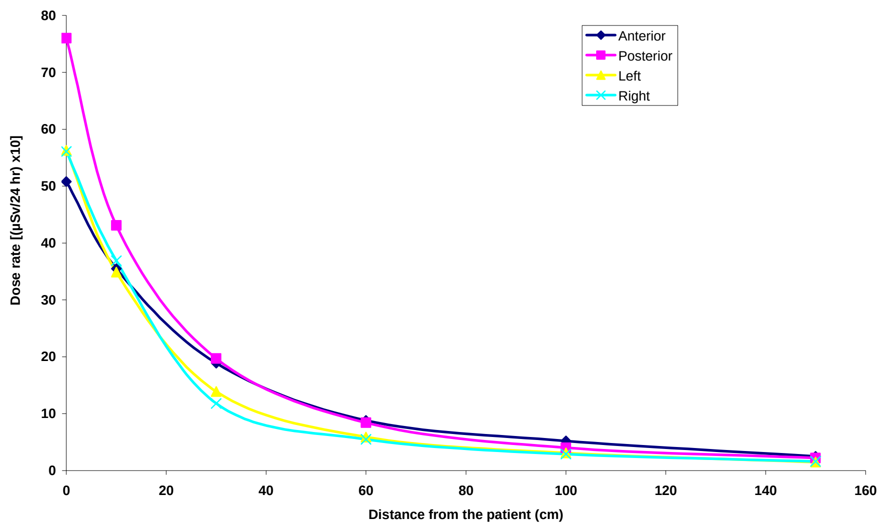

Fig. 1 : Radiation dose rates (µSv/24hr) to young infants, that measured from different sides and different distances from the parents for bone scan.

Figure 2

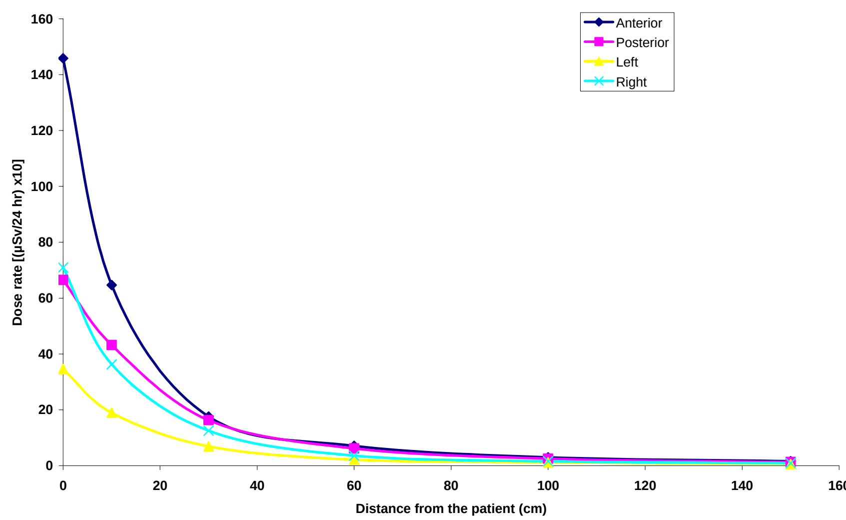

Fig. 2 : Radiation dose rate (µSv/24hr) to young infants, that measured from different sides and different distances from the parents for liver/spleen scan.

Figure 3

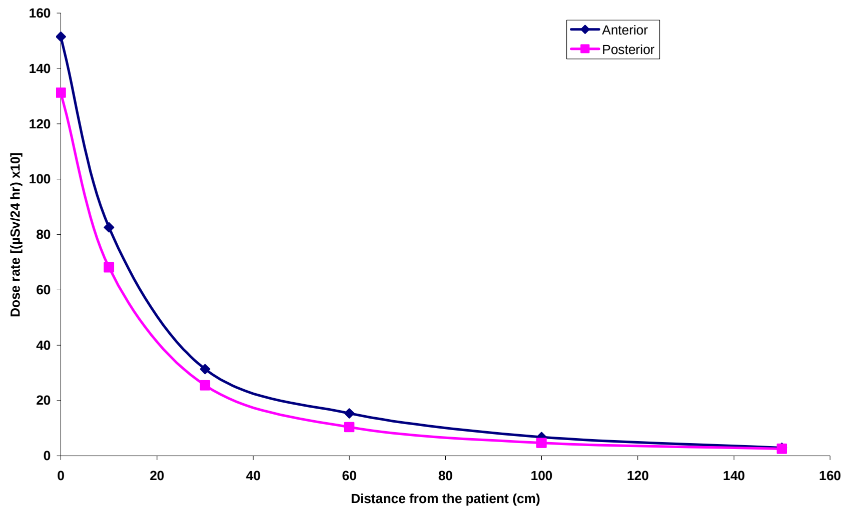

Fig. 3.: Radiation dose rate (µSv/24hr) to young infants, that measured from anterior and posterior sides and different distances from the parents for renal scan.

Figure 4

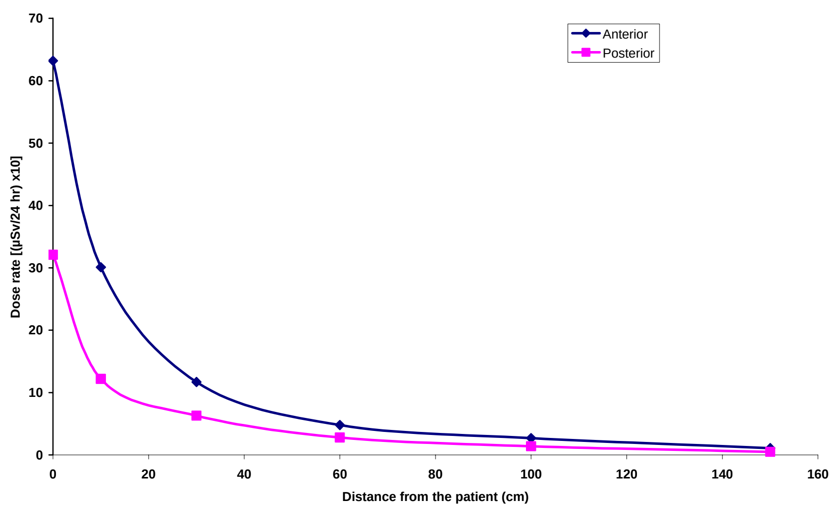

Fig. 4. Radiation dose rate (µSv/24hr) to young infants, that measured from anterior and posterior sides for different distances from the parents for thyroid scan.

The perception of risk is often subjective and biased by one's personal attitudes and past experiences. The "dose/effect" concept of radiation exposure is controversial. However, we believe that most scientist now agree that there is no threshold dose below which radiation-induced injury is absent. The question of radiation risk, *i.e.* radiation induced cancer, and the shape of its dose–effect relationship at very low doses is the subject of intense debate in the radiological protection community, especially because the International Commission on Radiological Protection (ICRP) prepared a revision of its Recommendations (ICRP, 2003). The article conducted by Brenner *et al.* (2003), makes it very clear that in order to quantify a risk of radiation for doses of lower than 10 mSv, impossibly large epidemiological studies would be necessary and the authors suggest that at lower doses inferences on risk need to be based on an understanding of the mechanisms of radiation action (Chadwick and Leenhouts, 2005), briefly presented a pathway of linkage using experimentally derived cellular and human data which associates a basic molecular lesion with the occurrence of cancer and which implies, on a mechanistic basis, that radiation risk is linear with dose from zero dose upwards. It is not possible to illustrate all the experimental evidence mentioned and readers should consult the quoted references for confirmation of the claims made (Chadwick and Leenhouts, 1981; Chadwick *et al.*, 2003).

DNA double strand break is the critical lesion leading to cellular effects and that a radiation induced mutation or aberration arising from a double strand break can ultimately lead to cancer so that the dose–effect for cancer induction is linear-quadratic, in general, but at low doses and low dose rates it is linear with dose from zero dose up (Chadwick and Leenhouts, 2005).

This has given rise to the ALARA (as low as reasonably achievable) principle of radiation protection. In keeping with this goal, we conducted this study in order to measure the radiation exposure that infant may anticipate receiving by being in close proximity to a radioactive parent.

Table 1, we notice that the doses obtained from the left side are less than those obtained from the anterior and posterior sides. All bone scan patients did void between the time of injection and the measurement. The measurement, therefore, represents the “best possible situation” or minimum exposure since voiding would be expected to decrease the patient’s radioactivity significantly (40%-50% of ^{99m}Tc-MDP is excreted in the urine) (Michael, 1990). For the thyroid, tissues that interfere between thyroid and the skin surface (from posterior side) are thicker than those interfere (from anterior side), for this reason the radiations that are emitted posteriorely from thyroid are more attenuated than those emitted anteriorely. Consequently, the dose rate that is measured from posterior side will be less than that measured from anterior side of the patient.

The value of T_{eff} which is introduced in this research to calculate the dose assumes that the total time of 9 hr was spread over 24 hr period as 35 minute at the start of each hour for the first 8 hrs after radiopharmaceutical administration, 35 minute at the start of each fourth hour for the next 12 h (i.e. feeding times overnight), and 35 minute at the start of each hour for the remaining 4 hrs. Estimates of close contact dose have been based on surface dose rates measured directly by an ionization chamber at a distance of 10 cm from the anterior mid-trunk of the patient (Mountford, 1987) and Mounford *et al*., 1991). It has been estimated that the close contact dose to a young infant from a parent who has undergone a diagnostic nuclear medicine procedure will be less than 1 mSv (the proposed new annual public dose limit) as long as the administered activity does not exceed the Administration of Radioactive Substances Advisory Committee (ARSAC) maximum value (Mounford *et al*., 1991).

The National Council on Radiation Protection and Measurements (ICRP) has recommended a maximum permissible dose (MPD) of 100 mrem/year (1 mSv) for the general population (Harding *et al*., 1985).

From Figure 1, we notice that the largest variations are associated with the liver/spleen measurements (with average variation of 66.5%), whereas the smallest variations are associated with renal measurements (with average variation of 20.6%).

By comparing our results with annual MPD for the public, referring to Table 1, we notice that the measured values for liver/spleen studies (anterior side at the skin), which is equal to 1.46 mSv (146 mrem) exceeds the MPD. Also for the renal studies, the results obtained for anterior and posterior sides (at the skin) which are equal to 1.52 and 1.31 mSv (152 and 131 mrem), exceed the annual MPD.

From liver/spleen measurements (as an example), we see the importance of taking into account the anterior side measurements. The large variation between anterior and left sides measurement emphasizes the taking into account the values obtained from all sides, whereas the measurements of the left side only were taken by other researchers (Michael, 1990 and ICRP, 1991).

When we search for a “conservative” values and concepts, concerning the radiation related to the radioactive patient, we believe that anterior and posterior sides values must be taken into account, especially for the cases (infants) that required measurements taken from positions in close proximity of the patient. There are several “common sense” radiation protection guidelines that may followed in order to minimize infant’s radiation exposure in dealing with radioactive parents, including encourage fluids and voiding, maximize distance from the patient. There remains one issue which is yet to be resolved in the evaluation of critical group dosimetry studies, regardless of whether these studies consist of measurements of integral dose, dose rates or even measurements of radioactivity expressed in breast milk samples.

The Administration of Radioactive Substances Advisory Committee (ARSAC) recommended interruption time for breast feeding for mature milk is 12 h after the administration of up to 80 MBq of ^{99m}Tc- MAA. In practice, volumes of colostrum expressed during the first 24–48 h post-partum are likely to be significantly below the assumed 850 ml day^{-1}. In this case the volume of early samples was only a few millilitres, increasing to less than 50 ml by 40 h (55 h post-partum). The expression of small volume samples is not expected to significantly affect the result since evidence suggests that radioactivity concentration is independent of volume of milk secreted (Rubow *et al.,* 1994). These data emphasize the need to make direct measurement of expressed samples on an individual patient basis, unless mature milk is being produced. To keep infant dose within the 1 mSv constraint (Department of health, London, 2000), the contribution from external irradiation must also be taken into account (McCauley and Mackle, 2002). This "cuddle dose" can be estimated from published data, using worst case assumptions, as 0.1 mSv (Mounford, 1997) and Mountford *et al*., 1991).

Even for just one set of exposure conditions, these studies will consist of measurements on a group of individuals, and therefore the results will contain a range of values. Experience has shown that these results may include a value which is very different to the remainder. This may due to unco-operative or otherwise exceptional behavior either by the patient or the exposed individual in the critical group. Basing radiation protection recommendations on a maximum value may result in unnecessary restrictions on clinical practice and on the behavior of patients. Although these recommendations should not be based on a mean or median result, agreement must be reached on the appropriate value for this basis which would be exclude an extreme value (e.g. 95% upper confidence limit) (Mounford, 1997).

Conclusions and recommendations

1. Any procedure employing ionizing radiation is usually performed only if alliterative diagnostic imaging modalities such as ultrasound and MRI cannot answer a specific test question appropriately (Harding *et al.,* 1994).
2. Any examination using ionizing radiation can be made only if the expected health benefit for the patient is significantly greater than the radiation risk. Excessive fear of radiation risk should not lead to refusal of justified examinations with possible subsequent serious health damage for the patient (Moser and Schober, 1994). There is no question that the nuclear risk-benefit equation resulting from medical exposure is tipped heavily in favor of benefit (Husak *et al*., 1999).
3. When we search for a “conservative” values and concepts, concerning the radiation safety associated with radionuclide patients, we believe that anterior and posterior sides values must be taken into account, especially for the cases that required measurements taken from positions in close proximity of the patient.
4. Agreement must be reached on the appropriate value of measurements which would be exclude an extreme value (e.g. 95% upper confidence limit) (Mountford, 1997).

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