Physica Medica xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Physica Medica

journal homepage: http://www.physicamedica.com

Original paper

Radiological protection of foetuses and breast-fed children of occupationally exposed women in nuclear medicine – Challenges for hospitals

A. Almén [a,b,*], S. Mattsson [a]

[a] Medical Radiation Physics, Department of Translational Medicine, Lund University, SE-205 02 Malmö, Sweden
[b] Radiation Physics, Department of Haematology, Oncology and Radiation Physics, Skåne University Hospital, SE-221 85 Lund, Sweden

ARTICLE INFO

Article history:
Received 30 January 2017
Received in Revised form 25 July 2017
Accepted 23 August 2017
Available online xxxx

Keywords:
Occupational exposure
Pregnancy
Breast-feeding
Radiation workers
Nuclear medicine
Radiation protection

ABSTRACT

This paper describes issues of concern for protecting foetuses and breast-fed children of occupationally exposed women in nuclear medicine from unnecessary exposure of ionising radiation. The protection principle is to ensure the same level of protection for the foetus and child as for the general public. Therefore international radiation protection standards recommend a dose constraint of 1 mSv to a foetus during the remaining time of pregnancy after it is known/declared and a yearly dose constraint of 1 mSv to a breast-fed child. It is not self-evident how to guarantee this level of radiation protection.

The exposure situation in nuclear medicine is complex. Exploring existing reported occupational exposure levels suggests great variability between work tasks and facilities. The standards and guidelines found give no detailed advice. Therefore each facility needs to systematically review external and internal exposure levels in order to plan appropriate protection measures and issue their own guidelines and rules. One strategy might be that each facility defines tasks that do not require any restrictions and lists such duties that are not suitable to do when pregnant or breastfeeding, taking also potential exposure levels into consideration. This paper gives examples of such types of work.

Information to the staff about the necessity of declaring pregnancy or breastfeeding is of fundamental importance. The internal policies issued by the hospital management should make clear the basis for taking care of pregnant and breastfeeding employees.

1. Introduction

Radiological protection of foetuses and breast-fed children of occupationally exposed women in nuclear medicine continues to be a topical issue due to the continuous change and advances of nuclear medicine. This is illustrated by continuing expansion of imaging technologies, such as positron emission tomography (PET) and hybrid imaging (PET/CT). Such changes create new challenges in radiological protection. The high proportion of female workers in healthcare; among technologists, radiographers, physicians, medical physicists, and biomedical engineers, emphasizes the need for a robust strategy regarding protection of foetuses and breastfed children in the healthcare sector.

Nuclear medicine uses a broad range of radiopharmaceuticals and radionuclides, including gamma- and beta-emitters with a wide range of electron and photon energies as well as alpha-emitters. The most prominent radiopharmaceuticals for diagnostic procedures are ^{99m}Tc-labelled substances (141 keV photons). Other radionuclides frequently used for planar imaging and single photon emission computed tomography (SPECT) are ^{123}I (153 keV) and ^{111}In (171; 245 keV). Hybrid imaging, using SPECT/CT and PET/CT, is now used on a large scale, having introduced X-rays into the nuclear medicine departments. Medical cyclotrons inside the hospitals are increasingly used for the production of short lived radionuclides (^{18}F, ^{11}C, ^{13}N, ^{15}O). The protons accelerated in the cyclotrons generate photons as well as neutrons due to nuclear reactions in different parts of the accelerator and a number of activation products are created. Well-established radioiodine treatments (using ^{131}I-iodide) for different benign metabolic thyroid disorders and for thyroid cancer are frequently performed. ^{89}Sr-chloride, and ^{153}Sm-EDTMP are used for treatment of metastatic bone disease. Radionuclide therapy using ^{177}Lu-octreotate is a routine treatment option for neuroendocrine tumours [1]. The alpha emitting radiopharmaceutical ^{223}Ra-chloride [2] is used for treat-

* Corresponding author at: Medical Radiation Physics Malmö, Department of Translational Medicine, Lund University, SE-205 02 Malmö, Sweden.
E-mail address: anja.almen@med.lu.se (A. Almén).

http://dx.doi.org/10.1016/j.ejmp.2017.08.010
1120-1797/

Please cite this article in press as: Almén A, Mattsson S. Radiological protection of foetuses and breast-fed children of occupationally exposed women in nuclear medicine – Challenges for hospitals. Phys. Med. (2017), http://dx.doi.org/10.1016/j.ejmp.2017.08.010

ment of bone metastases and emergent therapy methods using other alpha-emitting radionuclides, such as ^{227}Th and ^{211}At, are also present in some hospitals. The spectrum of radionuclides in use gives rise to a variety of radiation protection and occupational dosimetry challenges.

The work of the nuclear medicine staff includes a number of tasks such as preparing the radiopharmaceuticals, administering the activity, escorting patients, carrying out the examination and handling waste, sometimes also managing a cyclotron and working in a radiochemistry laboratory. The division of tasks between staff members differs between departments as well. Specific radiation protection measures in departments may also differ. Thus, individual exposure levels for workers can be expected to vary. It is obvious that the varying tasks are associated with different levels of external as well as internal exposure of the female worker and her possible foetus. The risk for the breastfed child to ingest radionuclides from breast milk is also significantly different, but the risk is low if appropriate radiation protection practises are observed when handling unsealed radionuclides. The management of appropriate radiological protection of foetuses and breastfed children of occupationally exposed women in nuclear medicine is challenging as the recommended dose constraint of 1 mSv for the foetus and child is significantly lower than the dose limits for workers with 20 mSv as a mean value for a 5-year period with a maximum of 50 mSv during one year [3].

This paper aims to critically review some issues of concern for protecting foetuses and breast-fed children of an occupationally exposed woman from unnecessary exposure of ionising radiation in nuclear medicine. The paper addresses the following;

a) Does reported staff dose data indicate work that is safe to carry out while pregnant or work that should be prohibited?
b) Which consideration should be given to potential exposure levels?
c) To what extent do radiation protection standards and available guidelines provide advice on how to practically arrange for proper and optimised protection in the clinic?

The paper also out-lines possible strategies and key issues when setting up local guidelines in the hospital.

The paper includes occupational dose data from three hospitals in Sweden during a 3 year period 2014–2016 as well as examples of published data. Information in international standards and published national standards and guidance documents has been included in the review.

2. Occupational radiation doses in nuclear medicine and implications on the assessment of foetal dose

Dose constraints for foetuses are given in dose equivalent (mSv) [4] in the United States [5] and in equivalent dose (mSv) [3] in the European Union [6]. In most cases in medicine both dose equivalent and equivalent dose is equal to mean absorbed dose as both the radiation weighting factor w_R and the Q-value are equal to 1 for photons and electrons.

2.1. Methods used for dose estimates

The mean absorbed dose to a foetus is related to the exposure of the woman. External exposure to the pregnant woman is characterised using the radiation protection quantity personal dose equivalent, $H_p(10)$, providing a conservative estimate of the effective dose to the exposed worker and also a conservative estimate of the mean absorbed dose to a foetus. The uncertainty of personal dose equivalent is significant and exceeds 50% at low dose levels [7]. For a month's measurement period, a value below about 0.1 mSv must be accurately measured, considering the dose constraint of 1 mSv. It is doubtful whether conventional personnel dosimeters meet that demand. Assessing the dose to the foetus only through measurements with personal dosimetry is thus difficult. Moreover, an assessment of the dose to the foetus in comparison to the workers' dose must be performed. Such assessments depend on depth dose measurements. Published data show that 1.3 mSv measured at the surface of the abdomen from ^{99m}Tc or ^{131}I is equivalent to approximately 1 mSv to the foetus [8]. For higher energy photons, such as those from positron emitting radionuclides, the dose to the foetus may be more similar to the dose measured at the surface of the abdomen. These assessments assume that surface dose and an estimated personal dose equivalent are equal, this is of course not true, but given the large uncertainties in personal dosimetry such simplifications may be acceptable.

The internal exposure of the pregnant woman and her foetus can be assessed by using whole body counters or through measurements on urine samples. However, whole body counters are only available in some hospitals. Possible inhalation, ingestion or uptakes through the skin could be assessed from environmental measurements, e.g. through measurements by portable or personal air samplers with carbon filters, or assessing contaminations in the localities, using wipe tests. However, the substances differ in chemical form and biokinetic behaviour and this influences possible internal exposure levels. The transfer across the placenta to the foetus and the excretion in breast milk has also to be known. The aspects to consider when assessing intake are many [9] and overall there is a need to set up guidelines for monitoring of individuals from intake of radionuclides [10]. The uncertainties regarding internal exposure to the workers and possible doses to the foetus and breast-fed child are therefore high.

Due to limitations in measurements of occupational exposure, the uncertainty in reported external dose values is considerable. This is also the case for the rare internal exposure data for occupationally exposed women. The assessment of foetal dose or the dose to the breast-fed child is even more uncertain. The need to improve methodology in assessments of foetal dose is apparent.

2.2. Available occupational exposure levels for different work activities

A worldwide mean annual occupational dose in nuclear medicine below 0.7 mSv has been reported [11], and the reported mean annual dose in different facilities is around this level. However, mean values do not reflect the dose distribution and more detailed dose data is needed for evaluating possible dose to a foetus. The more detailed description of dose data found are presented as: whole body dose per year or per procedure to workers, possible dose rates at different distances from the workplace or patient, or assessed dose per amount of activity administered. Such values have to be weighted together in order to assess a possible foetal dose.

In order to get a comprehensive view of occupational exposure levels due to external irradiation, data for the time period 2014–2016 regarding a larger healthcare region in Sweden was gathered and data from three hospitals was analyzed. For this period a total of 307 annual doses were registered. The data suggests substantial variation between different tasks. A summary of reported external whole body doses for this time period is presented in Fig. 1. All data on measured annual personal dose equivalent, $H_p(10)$ above 0.1 mSv is presented as a box plot giving median values, the third and first quartile, maximum and minimum values for different types of work. Group I consists of all personnel engaged. This group exhibits a median dose and a mean dose of 0.4 and 0.8 mSv per year, respectively. The interquartile distance is large. Group II con-

Please cite this article in press as: Almén A, Mattsson S. Radiological protection of foetuses and breast-fed children of occupationally exposed women in nuclear medicine – Challenges for hospitals. Phys. Med. (2017), http://dx.doi.org/10.1016/j.ejmp.2017.08.010