**Introduction**

The introduction of combined PET/CT has been an important advancement in the diagnosis, staging, monitoring, and treatment of various malignancies in adult and pediatric patients. This innovative technique allows for simultaneous PET and CT imaging, providing valuable information about both the metabolic activity and anatomic details of a lesion. It is widely used in the management of pediatric malignancies, raising the important issue of radiation exposure in children. The cumulative radiation dose from serial PET/CT studies is a concern, especially in pediatric patients who are at particular risk for developing secondary malignancies.

**Purpose**

To estimate the cumulative radiation dose from PET/CT studies to pediatric patients with malignancies.

**Methods and Materials**

248 clinical PET/CT studies performed on 78 patients (50 males/28 females, ages 3 to 18.5 years of age (Graph 1) between 12/2002 and 10/2007 were reviewed. Effective dose from CT was estimated using the InPACT Patient Dosimetry Calculator (www.inpactscan.org) (Version 0.99x) with patient specific scan parameters. It makes use of the NRPB Monte Carlo data sets produced in report SR250, which provides normalized dose data for irradiation of a mathematical phantom (MIRD phantom) by a range of CT scanners (1, 2). The specific parameters are available from the header of the DICOM file associated to each specific patient as shown in Table 1. Users can interactively select a scan start and end position using a diagram of the MIRD phantom provided (Figure 1). Effective dose was automatically calculated by entering all the parameters corresponding in an MIRD phantom. The CT dose was adjusted accordingly to age. The phantom used to produce the Monte Carlo data sets in NRPB report SR250 is based upon a mathematical representation of an ‘average’ adult, but does not address the issue of dose to pediatric patients. Monte Carlo calculations were performed on a range of phantoms corresponding to Newborn, 1 year old, 5 year old, 10 year old, 15 year old and adult patients (3).

Effective dose from PET was estimated using the OLINDA/EXM software (Vanderbilt University (Version 1.0)) with patient specific FDG doses. Dose estimates were adjusted for patient age according to published values. Olinda is a program to calculate internal radiation dose from PET scans used in nuclear medicine. The program has phantom libraries which permit the calculation of doses for individuals of different age and size (4), demographic and individualistic models need to be provided by the users. So F-18, which is the essential nuclide in FDG, was specified. An absorbed dose estimation study from F-18 FDG by Hays et al. was used as a kinetic model (5). Adult male, adult female, 15-year-old, 10-year-old, and 5-year-old models in OLINDA/EXM library were utilized for effective dose conversion factor (mSv/mCi). These factors were then interpolated according to different ages, shown in Table 2, and then multiplied by injected activity (mCi) for each PET study to get an estimation of effective dose.

**Results**

The average number of PET/CT studies per patient was 3.2 per patient (range: 1 - 14) (Graph 2). The average effective dose of an individual CT study was 20.3 mSv (range: 2.7 - 54.2) (Graph 3). Of PET/CT, the effective dose was 4.6 mSv (range: 0.4 - 7.7) (Graph 4) and PET/CT was 24.8 mSv (range: 6.2 - 60.7) (Graph 5). The average cumulative dose per patient from CT studies was 64.4 mSv (range: 2.7 - 326) (Graph 6), from PET studies was 14.5 mSv (range: 2.8 - 73) (Graph 7) and from PET/CT studies was 78.9 mSv (range: 6.2 - 399) (Graph 8). Radiation doses varied significantly depending on the number of studies as well as the number of additional CT scans performed. 58% (45 patients) received no radiation therapy and 42% (33 patients) received radiation therapy, 27% (21 patients) of all patients received >100 mSv cumulative dose; this consisted of 9% (7 patients) with no radiation therapy, and 18% (14 patients) with radiation therapy.

**Discussion**

The radiation exposure from PET/CT studies can be considerable, especially for those patients undergoing regular follow-up exams. Radiation doses vary significantly depending on the number of PET/CT studies performed.

The long-term effects of the treatment of pediatric malignancies are numerous and substantial. These include development of cardiomyopathies, avascular necrosis of the hip, cognitive delay, early onset of heart and pulmonary fibrosis and increased risk of secondary malignancies. Children who receive alkylating chemotherapeutic agents and radiation as part of their treatment regimens are at particular risk for developing secondary malignancies. The increasing use of PET/CT in the management of pediatric malignancies raises the important issue of radiation exposure in children. Particularly when it is reported that children have an increased risk of developing secondary malignancies from radiation exposure compared with adults. In fact, by extrapolating data from atomic bomb survivors, this increased risk is by an order of magnitude greater than that of adults. (Brenner article NEJM) Consequently, radiation exposure from PET/CT in children should adher to the ALARA principle (as low as is reasonably achievable) to the diagnostic information.

For patients who have received radiation therapy as part of their treatment (ie Hodgkin's disease and soft tissue sarcomas) the incremental radiation exposure from serial PET/CT studies is insignificant; however, for patients that do not receive radiation therapy then the radiologist must be certain that the patients who receive mantle radiation vs. limited radiation to a distal extremity for example the foot for a sarcoma, the cumulative dose to organs such as the lung, heart, thyroid, gonads, etc. is significant.

It is necessary to refine the ALARA principle (As low as is reasonably achievable) in the radiation exposure of PET/CT without sacrificing diagnostic information. For example this might involve reducing the tube current (mA) value on the CT portion to reduce dose but only to the level where diagnostic quality is preserved.

Furthermore, the use of PET/CT in children should be used on a case by case basis with particular emphasis on the risk, benefit and cumulative radiation dose to the pediatric patient.

Alternative CT or PET/CT limited to the area of interest, interrupted by periodic whole body PET/CT, whole body PET followed by limited CT in areas of PET positive lesions (albeit with some reduced sensitivity).

Whole body PET/CT continues to be an important non-invasive diagnostic/staging modality for certain malignancies such as Hodgkin and non-Hodgkin lymphomas and it is felt that alternative or more cautious approaches should be weighed against the unequivocal benefit provided.

**Conclusions**

The radiation exposure from PET/CT studies may be negligible in patients who receive radiation therapy, but is considerable in patients who do not receive radiation therapy. The ALARA principle can be achieved either by reducing the CT tube current or by considering alternative diagnostic approaches such as limited CT scan length or PET/MRI.

PET/CT remains an important non-invasive diagnostic, staging, and surveillance modality for certain pediatric malignancies. The decision to utilize PET/CT (and the frequency that it is used in an individual child) should be made with particular awareness to the cumulative radiation dose and its overall benefit.

**References**