Monte Carlo Simulation of In vivo Measurement of the Most Suitable Position of the Knee for the Most Accurate Measurement of the Activity

Khalaf M., Brey R., Jamse A., Claver K. , Derick S., Meldrum J.

Idaho State University, Pocatello ID;United States Transuranium and Uranium Registries, Richland WA;Portneuf Medical Advanced Center, Pocatello ID

Abstract

To assess the amount of activity in the knee and then in the skeleton, a suitable position of the leg by which all the knee bones contribute to detectable activity should be found. The aim of this study is to create a new and valid model for Monte Carlo simulation of invivo measurement of the knee in a position that optimizes conventional measurements.

The United States Transuranium and Uranium Registries (USTUR) case 0846 was a whole-body donation whose body size is very close to the reference man body dimensions, and could provide a unique opportunity to determine the full-lifetime biokinetics of Am-241 Oxide chronic inhalation. The USTUR case 0846 leg had been used in this work because it appears that the knee measurements are suitable and offer several advantages over other approaches to in-vivo measurements of Am-241. High resolution (0.2 mm) Computed Tomography (CT) images of the USTUR case 0846 leg at different positions were obtained. These images have been saved in DICOM format, and they have been segmented manually in preparation for voxelization and MCNPX input. The MCNPX code generated will be used to help validate various in-vivo measurement techniques. Front and lateral measurements for the knee of the USTUR case 0846 leg in a bent position and the same measurements with the leg in a straight position using a germanium detector were obtained. The results showed that the front measurement of a bent leg knee is optimal as it is the efficient measurement, giving the highest count rate when compared with other orientations.

Introduction

To assess and control the dose due to internal exposure of any radioactive materials, it is necessary to perform individual monitoring. The evaluation of internal contamination can be performed through different methods; among the most reliable methods are invivo monitoring. Various kinds of detection systems have been developed for invivo monitoring. Among them, invivo counting systems based on high purity germanium (HPGe) detectors which are widely used due to the advantages of their high energy resolution (Liye et al. 2007).

Estimations of detector efficiency used for invivo monitoring can be simply determined using phantoms (Lee and Lee 2006). The classical method applied for efficiency calibration is performed with physical phantoms that are loaded with known radionuclides and radioactivity. Because physical phantoms do not consider the special features of the individual structures of a human body, and the real activity distribution cannot be simulated exactly, many questions are raised about using physical phantom in this way. To solve this problem, computational phantoms are developed to represent the human body at a given age, and having all appropriate internal and external anatomy. Two main classes of computational phantoms exist for use in various organ dose evaluation purposes: stylized (or mathematical) phantom and tomographic (or voxel) phantom (Hegenbart 2010).

Materials and Methods

On a long-term basis, americium is known to be a bone seeking element. In-vivo measurement will therefore focus on the detection of activities in the skeleton. Especially, if as in the present case (USTUR case 0846), the contamination occurred many years ago. It appears that knee measurements are suitable and offer several advantages over other to in-vivo measurements of Am-241. However, because bones are mechanically stressed and this modifies the patterns in which americium is deposited and retained within the bone material, the result must be evaluated carefully.

Case of Am-241 Contamination

USTUR case 0846, involved a gentleman who was a glove-box operator. This individual had prepared an estimated 50 pressed gold foils, each containing 200 mg of Americium Oxide powder. This person was repeatedly internally contaminated, most probably by Am-241 Oxide via inhalation (chronic inhalation). The initially estimated 241AmO2 body burden was about 37 kBq.

Argonne National Laboratory (ANL) measurements indicated that the individual's total body burden of Am-241 was about 67 kBq i.e. 36 times the then recommended maximum permissible body burden (MPBB) or 1.85 kBq of americium. Such a deposition was projected to possibly deliver tens of thousands of rem to bone surfaces during the remaining lifetime of the patient. The registries 34th whole body donor (USTUR 0846) passed away at age 72 (USTUR 2009).

CT Scan

The leg was scanned in two different positions; straight and bent (Figure 1). Using a Toshiba 16 Slice Scanner owned and operated by the Portneuf Medical Advanced Imaging Center, the leg was scanned completely. Image reconstruction was performed with a grid 512×512 and pixel width of 0.781-mm. The slice thickness was set at 2-mm. 518 images of the leg in straight position and 346 images of the leg in bent position were obtained. All the images were saved in DICOM format.

Fig.1: CT scan of the leg at two different position (A: straight position, B: bent position).

Experimental Measurements

To perform direct measurements of the USTUR case 0846 leg, a holder was constructed specially for the purpose of holding the leg in different positions and on different sides. The holder and the detector were adjacent to avoid variation in the distance between the detector and the leg when different but reproducible measurements of the leg were taken (Figure 2).

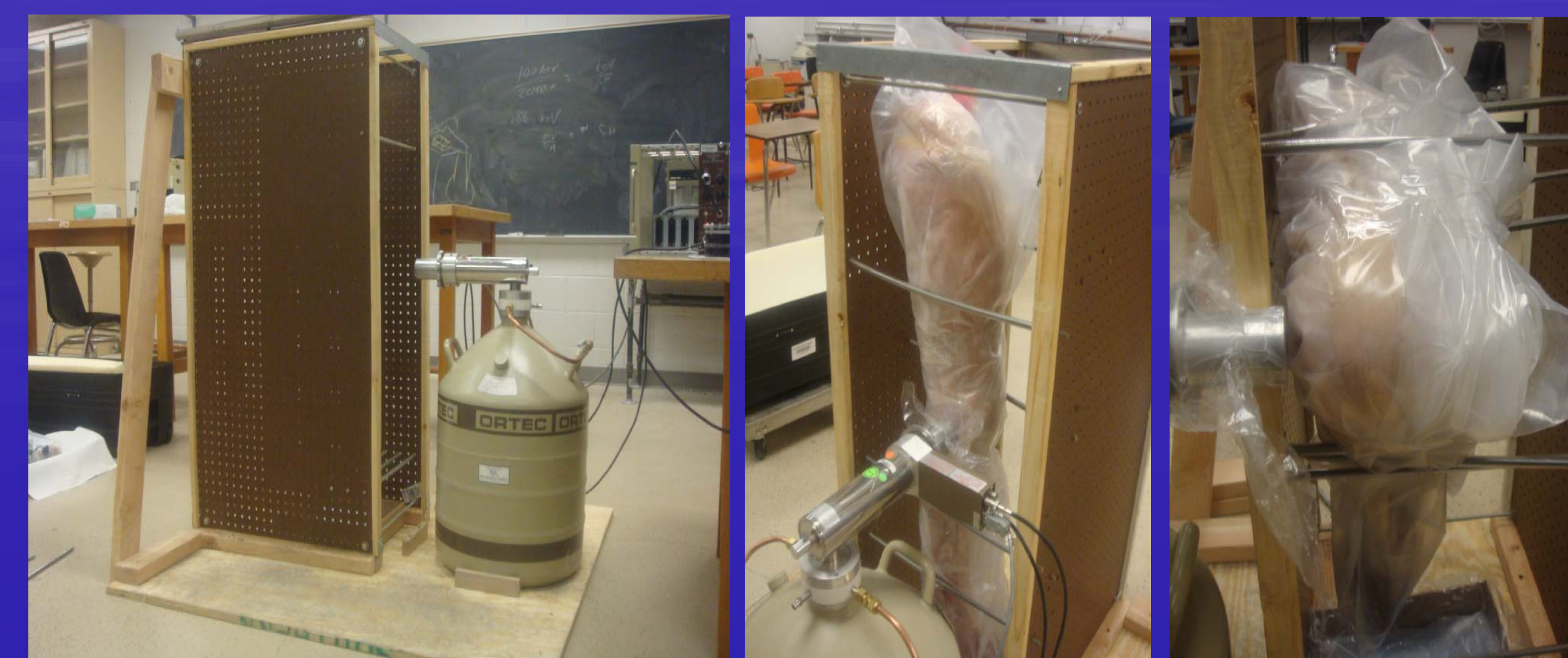

Fig.2: The holder and the detector used for measurements.

The detector chosen for these measurements was a HP(Ge) ORTEC N-type **,** with a beryllium thin entrance window (0.127-mm), a thin dead layer (only 0.3-μm), and a resolution of 0.233 keV at the 5.9-keV Fe-55 and 0.5 keV at the 122-keV Co-57.

Four different 10-hours measurements were conducted. A constant distance of 4 mm was maintained between the knee and the detector. The different positions in which the USTUR case 0846 leg was analyzed using a Germanium detector were as follows:

Front measurement of the knee with the leg in the straight position (Figure 3A).

Lateral measurement of the knee with the leg in the straight position (Figure 3B).

Front measurement of the knee with the leg in the bent position (Figure 3C).

Lateral measurement of the knee with the leg in the bent position (Figure 3D).

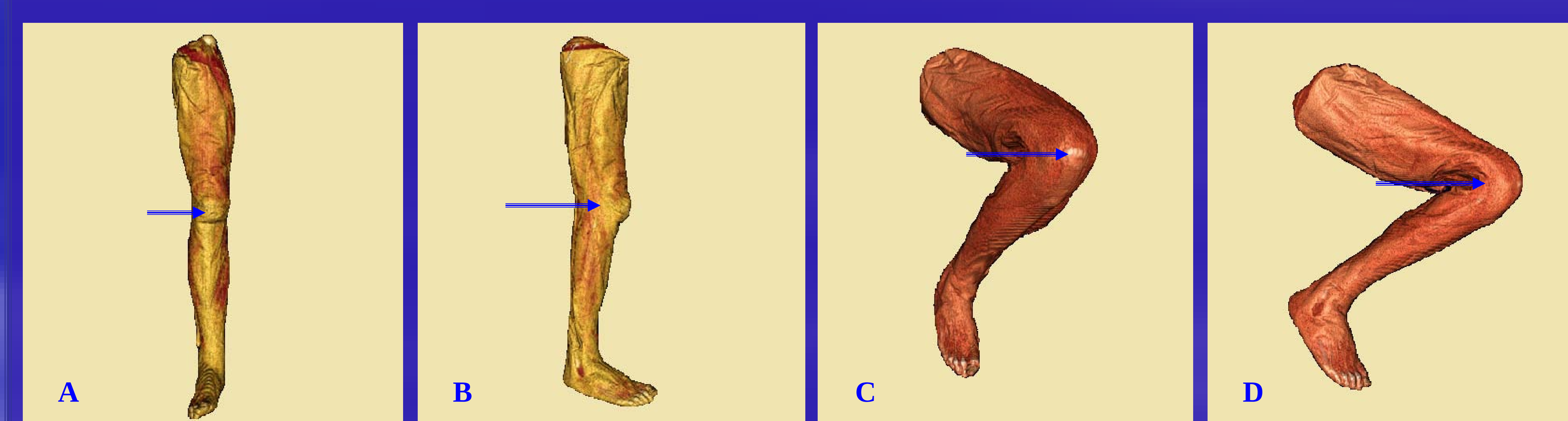

Fig.3: Leg position through the measurements (the images obtained from CT scan of USTUR case 0846 leg).

Background activity measurements were taken into account. So the same measurements (position, time, distance) were performed using a cadaver leg with approximately the same weight, height, and age as USTUR case 0846 leg.

Segmentation

Segmentation is the process performed to assign every voxel to the appropriate organ or tissue. This will be done using appropriate image processing software which is employed to identify tissues based on CT separation.

After CT, the resultant images were imported into 3D-Doctor (Able Software Corp.). A 3D modeling and image-processing software for tomography data. With this software, organs of interest will be segmented manually within each pixel CT image. Tissues variety and layers of the real leg and at the same time the simplicity of the phantom leg make segmentation of CT scan images for the real leg (USTUR case 0846) more challenging than segmentation of CT scan images for a physical phantom leg. According to the CT image resolution of the USTUR case 0846 leg and ICRP 110 recommendations on computational voxel phantoms (ICRP 2009), the regions of interest need to be divided into the following sections:

- **For the tissue:** Skin, Adipose tissue, Muscle tissue, Blood vessels, and Lymphatic nodes.
- **For the bone:** Cortical bone (outer shell), Spongiosa (traeucular bone, red bone marrow, and yellow bone marrow), Mudullary cavity (enclosed by cortical bone), and Bone cartilage.

To account for the non-uniform distribution of radioactive materials in different parts of the leg bones, and to match radiochemical analysis, the leg bones will be divided into several tissue pieces during the segmentation as shown in Table 1 (USTUR 2009). A total of 36-individual objects were segmented in the USTUR case 0846 leg. Segmentation will be saved as a project file. The project file in the end is exported to a boundary file and saved.

Table 1: List of items case number 0846, which summaries radiochemical analysis of skeletal: leg (USTUR 2009).

Tissue Type	Sample #	Tissue piece (right leg)	Prepared Mass/Volume (gm)
Skeletal: Leg	206	Femur: Proximal End	191.46
Skeletal: Leg	207	Femur: Proximal Shaft	145.75
Skeletal: Leg	208	Femur: Mid Shaft	110.60
Skeletal: Leg	209	Femur: Distal Shaft	141.29
Skeletal: Leg	210	Femur: Distal End	232.57
Skeletal: Leg	211	Patella	39.36
Skeletal: Leg	212	Tibia: Proximal End	164.14
Skeletal: Leg	213	Tibia: Proximal Shaft	174.25
Skeletal: Leg	214	Tibia: Distal Shaft	111.89
Skeletal: Leg	215	Tibia: Distal End	80.04
Skeletal: Leg	216	Fibula: Proximal End	13.25
Skeletal: Leg	217	Fibula: Proximal Shaft	27.90
Skeletal: Leg	218	Fibula: Distal Shaft	32.10
Skeletal: Leg	219	Fibula: Distal End	19.54
Skeletal: Foot-Ankle	220	Foot & Ankle	376.99

Voxelization and Creation of the MCNP Input file

The voxel lattice editor, which is a program developed by the Human Monitoring Laboratory (HML) is employed to voxelize segmented images and convert these voxel files into MCNP input files (Kramer et al. 2010). Input files are based on several things including: (1) The voxel phantom obtained from CT scan images of the USTUR case 0846 leg, which is non-uniformaly loaded with Am-241 in a fashion consistent with radiochemical analysis of the leg bones;(2) a description of the HP(Ge) detector that has been used for these measurements;(3) the time of measurements;(4) the position of the detector with respect to the knee; and (5) the distance between the detector and the knee. The products of this effort are four output files (one for each position) and four different counting efficiencies of the detector corresponding to the relative position of the knee. The estimated geometric efficiencies demonstrate which measurement position is optimal to assess the activity in the knee and then in the skeleton. The numerical efficiency (model) is validated by comparing it with the detector efficiency obtained from experimental measurements and the radiochemical analysis of the knee bones.

Results and Discussion

CT scan images of the leg (USTUR case 0846) at different positions with a good resolution (2-mm) were obtained. These images have been saved in DICOM format. The DICOM images are in the process of being segmented manually to prepare than for voxelization and use as an MCNP input file for numerical calibration of the in-vivo measurement. The objective is to determine the optimal position of the knee and the most accurate measurement of activity in the knee. All experimental measurements of the leg using a HP(Ge) detector were obtained. A difference among counts obtained from different geometrical configurations was observed (Table 2). Front measurement of the knee with the leg in a bent position gave the highest count rate when compared with the others, while measurement of the knee with the leg in the straight position had the lowest count rate.

Table 2: Measurements of the knee using HP(Ge) detector with different position of the leg.

	USTUR case 0846 Leg Measurements (counts at 59.54 keV)
Bent leg position (Front Measurements)	22258.3 ± 196.81
Straight leg position (Lateral measurements)	20549.7 ± 186.31
Bent leg position (Lateral Measurements	20456.6 ± 192.92
Straight leg position (Front measurements)	19640 ± 194.10

Conclusion

Case 0846 represents an individual who was repeatedly internally contaminated by Am-241 via chronic inhalation many years earlier. In-vivo measurements were performed on the leg of USTUR case 0846 Front measurement for the knee of a bent leg position using a HP(Ge) gave the highest count rate. These observation lead to a conclusion that the knee measurement of a bent leg position is optimal to approximate the real amount of activity in knee bones and then in the whole skeleton. Monte Carlo modeling of this geometry continuous.

References

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