Towards patient-specific dosimetry in nuclear medicine associating Monte-Carlo and 3D voxel-based approaches

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Radiation Protection: Accurate and realistic dosimetry

MIRD Formalism

\[
\overline{D}_{r_T} = \sum_{r_S} \tilde{A}_{r_S} \times \sum_i n_i E_i SAF(r_T \leftarrow r_S)
\]

Biokinetic aspect

Geometric aspect

\[
SAF(r_T \leftarrow r_S) = \frac{E_T/E_S}{M_T}
\]
Tabulated reference data

SAFs tabulated for mathematical standard geometries

Approximations applied for electron SAFs

Target region = Source region

\[ SAF(C \leftarrow S) = \frac{1}{mass_{source}} \]

Target region ≠ Source region

\[ SAF(C \leftarrow S) = 0 \]

Walled source regions

\[ SAF(C \leftarrow S) = \frac{1}{2 \times mass_{source}} \]
Optimisation

New adult reference computational phantoms of the ICRP

Male phantom

Female phantom

Publication 110 of the ICRP

Monte Carlo calculations

SAFs
Photons + Electrons
(10 keV<E<10MeV)

HMGU
(EGSnrc)

QUALITY ASSURANCE

IRSN
(MCNPX +OEDIPE)

Absorbed doses from radiopharmaceuticals

Standard biokinetic of 11 radiopharmaceuticals used in nuclear medicine

Context Results - SAF Results – Reference doses Results - Patient-based doses

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Reference phantoms ➔ Fixed geometry

Influence of MORPHOLOGY on dose calculations
RESULTS

SAF Calculations
Comparison between voxelized and ORNL phantoms
PHOTONS, SAF (Lungs < Liver), Male

Low energies
Ratio
Voxelized/ORML \( \rightarrow 25 \)

Different shapes and inter-organ distances

High energies
Ratio
Voxelized/ORML \( \rightarrow 1.5 \)

Small influence of the organ shapes on the SAFs
ELECTRONS, SAF (Lungs <- Lungs), Male

Prior approximations

\[ \text{SAF}(\text{Lungs} \leftarrow \text{Lungs}) = \frac{1}{m_{\text{Lungs}}} \]

\[ m_{\text{Lungs}} = 1 \text{ kg} \]

Ratio

\[ 0.99 < \frac{\text{EGSnrc}}{\text{MCNPX}} < 1.01 \]

Low energies:

\[ \text{SAF} \rightarrow 1 \]

High energies:

Electron escape
• **Photon SAFs**

**Cross-fire:** for many organ pairs, voxel phantom SAFs higher than current values based on mathematical phantoms (inter-organ distances are larger in mathematical phantoms than in reality)

• **Electron SAFs**

**Self-absorption:** higher-energetic electrons escape, especially from small organs

**Cross-fire:** SAFs can approach nearly the same order of magnitude as photon SAFs for higher electron energies and organs in close vicinity
RESULTS

Dose Calculations
Mathematical versus computational reference phantoms
Reference voxel phantoms

Standard biokinetic of radiopharmaceuticals (ICRP 53 + ICRP 80 + ICRP 106)

Absorbed doses for 11 radiopharmaceuticals used in nuclear medicine
Absorbed doses
Mathematical versus voxel reference phantoms

Differences depend on target organ and radiopharmaceutical

**$^{11}$C-Methionine**
- Female: 56% (uterus)
- Male: 59% (Urinary bladder wall)

**$^{131}$I - thyroid uptake 55%**
- Female: 306% (lungs)
- Male: 272% (lungs)

**Reasons**
- **Geometric:** topology and distances between organs
- **Physic:** approximations previously used for electrons transport
RESULTS

Dose Calculations

Mathematical phantoms using OLINDA/EXM versus patient-based phantoms using OEDIPE
Creation of the patient-based voxel phantoms

Segmentation of 27 organs

TPS ISOGray™ DOSIFX-soft

Specific voxel phantoms

Voxelization

Attribution of the densities

Creation of a voxel phantom: ~ 8H
<table>
<thead>
<tr>
<th>6 female phantoms</th>
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Absorbed doses for $^{18}$F-FDG for male phantoms

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Determination of patient-based doses: between $9^H$ and $16^H$

OEDIPE + MCNPX

Maximum absorbed dose differences among patients: factor 3.4

Maximum dose differences between patient-based phantoms and
Reference mathematical phantoms: ~400% (walled organs)
174% (brain for $^{131}$I_55%)
Reference voxel phantoms: 113% (thyroid for $^{131}$I_55%)
Isodoses curves superimposed on anatomical images

Absorbed dose to target organs or tumors

DVH
Thank you for your attention

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