Dose Optimization in Pediatric Patients

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BEST HOSPITALS
U.S. News & WORLD REPORT
RANKINGS
2015-2016
Number 1
MASSACHUSETTS GENERAL HOSPITAL
Rehani, IPET Optimization children
1. Massachusetts General Hospital, Boston
2. Mayo Clinic, Rochester, Minnesota
3. (tie) Johns Hopkins Hospital, Baltimore
3. (tie) UCLA Medical Center, Los Angeles
5. Cleveland Clinic
6. Brigham and Women's Hospital, Boston
7. New York-Presbyterian University Hospital of Columbia and Cornell, New York
8. UCSF Medical Center, San Francisco
9. Hospitals of the University of Pennsylvania-Penn Presbyterian, Philadelphia
10. Barnes-Jewish Hospital/Washington University, St. Louis
11. Northwestern Memorial Hospital, Chicago
12. NYU Langone Medical Center, New York
13. UPMC-University of Pittsburgh Medical Center
14. Duke University Hospital, Durham, North Carolina
15. Stanford Health-Stanford Hospital, Stanford, California
Learning Objectives

1. To understand the specific needs for dose optimization in children
2. Become familiar with strategies and approaches for dose optimization in nuclear imaging in particular PET
3. Become familiar with strategies and approaches for dose optimization in CT imaging
Educational Objectives

1. To understand the specific needs for dose optimization in children

2. Become familiar with strategies and approaches for dose optimization in nuclear imaging in particular PET

3. Become familiar with strategies and approaches for dose optimization in CT imaging
Are Children more sensitive to radiation than adults?
Traditionally

• Traditionally, it has been believed that children are

• Why?
  – Longer life expectancy to manifest
  – Developing and growing tissues

• Is there data to indicate that for the same absorbed radiation dose children show higher radiation effects than adults?
• Notion that children might be two–three times more sensitive to radiation than adults is only partly true.

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Radio-sensitivity of children (UNSCEAR)

• Children are clearly more radiosensitive for about 30 per cent of tumour types when compared with adults.

• These types include
  – Leukaemia
  – Thyroid
  – Skin and
  – Brain cancer.
Radio-sensitivity of children (UNSCEAR)

• They have the **same sensitivity** as adults when it comes to **25 per cent of tumour types** such as
  – Kidney and bladder,

• They are **less sensitive** than adults when it comes to **10 per cent of tumour types** including **lung cancer**.
Radio-sensitivity of children (UNSCEAR)

• For about 15% of tumour types (including oesophagus cancer), the data are too weak to draw a conclusion regarding differences in risk with age at exposure.

• Finally, for about 20% of tumour types (including myeloma, Hodgkin’s disease, prostate, rectum and uterus cancer), there is only a poor or no relation between radiation exposure and risk.

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What radiation risks?

• Tissue injuries (skin): Interventional procedures

• Other tissue injuries (deterministic effects)

• Carcinogenic risk
Past

Benefit-risk ratio was almost always considered to be in favor of benefit
Do not worry about radiation risk from diagnostic examinations, the risks are minimal and much smaller as compared to benefit.

Risk of not doing exam may be higher than risk of doing exam

BUT..........
Now

• I have a child of 3 yrs who has undergone 3 CT scans in last 6 months and a PET/CT
• I have to decide about next CT scan
• What is your advice on risk?
Do not worry. The risk of not doing the exam is higher than risk of doing exam

Can one make above statement? - NO
That is what provides motivation for the talk today
Cumulative Effective Doses From Radiologic Procedures for Pediatric Oncology Patients

Bilal A. Ahmed, Bairbre L. Connolly, Pumeet Shroff, Amy Lee Chong, Christopher Gordon, Ronald Grant, Mark L. Greenberg and Karen E. Thomas

*Pediatrics* 2010;126;e851; originally published online September 27, 2010;
DOI: 10.1542/peds.2009-2675

**RESULTS:** Individual CED estimates ranged from <1 mSv to 642 mSv, with a median of 61 mSv. CT and NM were the greatest contributors; CT constituted 30% of procedures but 52% of the total CED, and NM constituted 20% and 46%, respectively. There was considerable variability between tumor subgroups. CED estimates were highest in the neuroblastoma (median: 213 mSv [range: 36–489 mSv]) and lymphoma (median: 191 mSv [range: 10–642 mSv]) groups and lowest in the leukemia group (median: 5 mSv [range: 0.2–57 mSv]).
We are dealing with situations that cannot be called as exaggeration.

When you do not know, exercise caution.

Perform exam only when necessary - Justification
Perform exam with minimal dose necessary - Optimization
Learning Objectives

1. Understand the specific need for dose optimization in children
2. Become familiar with strategies and approaches for dose optimization in nuclear imaging
3. Become familiar with strategies and approaches for dose optimization in CT imaging
Radiation dose

NM

- **Administered activity**
- Acquisition and processing: No direct impact on dose.
- Some hardware and software can allow to reduce admin activity

CT

- Acquisition protocols, hardware and software all affect dose
- mA
- kVp
- Pitch
- ........
• Weight in children can vary by a factor of more than 300 from a premature infant to an obese adolescent
• The paediatric task group of the EANM suggested in 1990 that activity given to children should
  – be calculated as a weight-dependent fraction of the activity given to adults, irrespective of the applied tracer
• To determine whether the correction factors proposed by the EANM result in weight-independent count rates or
• weight-independent effective doses;
• secondly, to determine whether only one dosage card is sufficient for the use of 95 different radiopharmaceuticals, and, if not, how many dosage cards?
Clusters

• Jacobs et al. studied 10 clusters and then pooled them into 3 as:
  – B: all remaining tracers, except
  – iodine labelled tracers for thyroid studies and $^{89}$Sr for therapy, which belong to cluster C.
Jacobs et al. Conclusions

- Correction factors proposed by the EANM mainly correct for effective dose.
- They are very similar to the factors obtained for cluster A.
- Using the EANM factors for tracers belonging to clusters B and C results in significantly higher effective doses to children.
- They suggest using three tracer-dependent dosage cards for which the correction factors have been calculated to obtain weight-independent effective doses.
## Dosage Card (Version 1.2.2014)

### Multiple of Baseline Activity

<table>
<thead>
<tr>
<th>Weight kg</th>
<th>Class A</th>
<th>Class B</th>
<th>Class C</th>
<th>Weight kg</th>
<th>Class A</th>
<th>Class B</th>
<th>Class C</th>
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<tr>
<td>6</td>
<td>1.47</td>
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<td>1.71</td>
<td>2.14</td>
<td>3.00</td>
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<td>4.18</td>
<td>8.43</td>
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\[
A_{\text{MBq}} = \text{Baseline Activity} \times \text{Multiple}
\]

Shahrij, IRT Optimization children
<table>
<thead>
<tr>
<th>Radiopharmaceutical</th>
<th>Class</th>
<th>Baseline Activity (for calculation purposes only)</th>
<th>Minimum Recommended Activity</th>
<th>MBq</th>
<th>MBq</th>
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<td>$^{123}$I (Thyroid)</td>
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<td>10</td>
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<td>$^{18}$F FDG-PET torso</td>
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<td>$^{18}$F FDG-PET brain</td>
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<td>$^{18}$F Sodium fluoride</td>
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<td>$^{67}$Ga Citrate</td>
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<td>$^{99m}$Tc ALBUMIN (Cardiac)</td>
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<td>B</td>
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<td>$^{99m}$Tc COLLOID (Marrow)</td>
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<td>$^{99m}$Tc DMSA</td>
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<td>$^{99m}$Tc DTPA (Normal renal function)</td>
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<td>20</td>
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<tr>
<td>$^{99m}$Tc MAA / Microspheres</td>
<td>B</td>
<td>5.6</td>
<td>10</td>
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<tr>
<td>$^{99m}$Tc MAG3</td>
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<td>$^{99m}$Tc MDP</td>
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<td>35.0</td>
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<td>$^{99m}$Tc Pertechnetate (Cystography)</td>
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<td>$^{99m}$Tc Pertechnetate (Ectopic Gastric Mucosa)</td>
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<td>$^{99m}$Tc Pertechnetate (Cardiac First Pass)</td>
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<td>35.0</td>
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<tr>
<td>$^{99m}$Tc Pertechnetate (Thyroid)</td>
<td>B</td>
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<td>$^{99m}$Tc RBC (Blood Pool)</td>
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<td>63.0</td>
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</tbody>
</table>
Paediatric radiopharmaceutical administration: harmonization of the 2007 EANM paediatric dosage card (version 1.5.2008) and the 2010 North American consensus guidelines

Michael Lassmann · S. Ted Treves ·
For the EANM/SNMMI Paediatric Dosage Harmonization Working Group
EANM

• 2006: EANM published a new version of their paediatric dosage card for 39 radiopharmaceuticals.
• 2008 an amendment with respect to the use of FDG was introduced
• An online dosage calculator was released by the EANM (http://www.eanm.org/publications/dosage_calculator.php?navId=285).
• 2012: As an offshoot of a recent project of the European Union (www.peddose.net), an App for iPhone/iPad (iAPP) was created for facilitating the calculation of administered activities.
EANM and SNMMI

• During the 2012 EANM congress a joint EANM, SNMMI working met to study the possibility of harmonizing the guidelines published by the two societies.

• The purpose of this work was to identify differences between these guidelines and suggest changes in both guidelines to achieve a level of harmonization between the two.
• For administered activities of $^{18}$F radiopharmaceuticals, there is a difference between theoretical results and a study in human subjects of various ages. As more data are collected, it is likely that somewhat lower administered activities will be defined for $^{18}$F radiopharmaceuticals for use in infants and smaller children.
Changes in EANM card to harmonize

• Assign class B to DMSA
• Change the baseline activity to 6.8 MBq
• Change the minimum recommended activity to 18.5 MBq
Change in North American consensus guidelines

• The guidelines will state additionally that the EANM dosage card may also be used.

• In addition, whether the maximum recommended activity can be set to 100 MBq should be checked.
**Table 1** Activity values and effective doses for renal cortical scan with $^{99m}$Tc-DMSA (ICRP 80 [7])

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1 year</td>
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<tr>
<td>Nominal weight (kg)</td>
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<tr>
<td>2007 EANM dosage card [1]</td>
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<tr>
<td>Administered activity (MBq)</td>
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<tr>
<td>Effective dose (mSv)</td>
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<tr>
<td>North American consensus guidelines [3]</td>
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<tr>
<td>Administered activity (MBq)$^a$</td>
<td>18</td>
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<tr>
<td>Effective dose (mSv)</td>
<td>0.68</td>
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<tr>
<td>2014 EANM dosage card$^b$</td>
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<tr>
<td>Administered activity (MBq)</td>
<td>18</td>
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<tr>
<td>Effective dose (mSv)</td>
<td>0.68</td>
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</tbody>
</table>

$^a$ 1.85 MBq/kg  
$^b$ Changes to the 2007 version (as denoted in orange in Fig. 1)  
$^c$ Minimum activity of the respective guideline
Table 5  Activity values and effective doses for $^{18}$F-FDG PET of the torso (ICRP 106 [10])

<table>
<thead>
<tr>
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<th>Age</th>
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<tr>
<td></td>
<td>1 year</td>
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<tr>
<td>Nominal weight (kg)</td>
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<td>2007 EANM dosage card [1, 2]</td>
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<td>Administered activity (MBq)</td>
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<td>Effective dose (mSv)</td>
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<td>North American consensus guidelines [3]</td>
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<td>Administered activity (MBq)$^a$</td>
<td>51</td>
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<tr>
<td>Effective dose (mSv)</td>
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$^a$ 5.2 MBq/kg
Changes deliberated/suggested in

1. Radionuclide cystography
2. Gastric emptying/reflex
3. Whole body $^{123}$I- MIBG scan
4. FDG-PET torso
5. FDG-PET brain
6. $^{18}$F-Sodium Fluoride
<table>
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<tr>
<th>Radiopharmaceutical</th>
<th>Administered Activity/kg</th>
<th>Minimum Administered Activity</th>
<th>Maximum Administered Activity</th>
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<tr>
<td>$^{123}$I-MIBG</td>
<td>[A] 5.2 MBq/kg 0.14 mCi/kg</td>
<td>37 MBq 1.0 mCi</td>
<td>370 MBq 10.0 mCi</td>
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<tr>
<td>$^{99m}$Tc-MDP</td>
<td>[A] 9.3 MBq/kg 0.25 mCi/kg</td>
<td>37 MBq 1.0 mCi</td>
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<tr>
<td>$^{18}$F-FDG</td>
<td>[A, B] Body, 3.7-5.2 MBq/kg 0.10-0.14 mCi/kg</td>
<td>26 MBq 0.7 mCi</td>
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<td></td>
<td>Brain, 3.7 MBq/kg 0.10 mCi/kg</td>
<td>14 MBq 0.37 mCi</td>
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<tr>
<td>$^{99m}$Tc-DMSA</td>
<td>[A] 1.85 MBq/kg 0.05 mCi/kg</td>
<td>18.5 MBq 0.5 mCi</td>
<td>100 MBq 2.7 mCi</td>
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<tr>
<td>$^{99m}$Tc-MAG3</td>
<td>[A, C] Without flow study, 3.7 MBq/kg 0.10 mCi/kg</td>
<td>37 MBq 1.0 mCi</td>
<td>148 MBq 4.0 mCi</td>
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<tr>
<td></td>
<td>[A] With flow study, 5.55 MBq/kg 0.15 mCi/kg</td>
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</tbody>
</table>

Please also see the notes at the end of this guideline (*).
Go with the Guidelines!

Follow the new North American Guidelines for Pediatric Nuclear Medicine for high quality images at low radiation dose.

Frederic H. Fahey¹, Sonja I. Ziniel²-⁴, Dacie Manion⁵, and S. Ted Treves¹

¹Division of Nuclear Medicine and Molecular Imaging, Department of Radiology, Boston Children’s Hospital, Harvard Medical School, Boston, Massachusetts; ²Center for Patient Safety and Quality Research, Program for Patient Safety and Quality, Boston Children’s Hospital, Harvard Medical School, Boston, Massachusetts; ³Division of Adolescent and Young Adult Medicine, Boston Children’s Hospital, Harvard Medical School, Boston, Massachusetts; ⁴Department of Pediatrics, Harvard Medical School, Boston, Massachusetts; and ⁵Massachusetts Institute of Technology, Cambridge, Massachusetts
Impact of N American Guidelines

- 13 dedicated pediatric institutions (US, Canada)
- Compared results of 2007 and 2013
- Administered activities of 16 NM procedures

- **2007**: The administered activity per unit of body mass and the maximum administered activity varied on average by a factor of 3 across institutions.
• 2007 (contd): The minimum administered activity varied on average by a factor of 10 and by as much as a factor of 20 in one case
• 2013: In general, the 13 pediatric institutions have reduced their administered activities in children
• Ten of the 13 institutions reported that they adjusted their administered activities according to the North American guidelines.
Approach used

• Initial survey indicating wide variation in practice on administered activity in children
• Development of North American consensus guidelines
• “Image Gently” campaign with support from the SNMMI an extensive public relations campaign entitled “Go with the Guidelines,”
• Deliver a poster of the guidelines to every nuclear medicine clinic in the United States and Canada.
• The poster published in several major nuclear medicine and imaging journals (The Journal of Nuclear Medicine, Journal of Nuclear Medicine Technology, Radiology, and Pediatric Radiology).

• The EANM established a pediatric dose project (PEDDOSE) around this same time that led to the development and distribution of the EANM pediatric dosage card.
Familiar versus modifying practice

• Even though all the institutions reported that they were familiar with “Image Gently” and the North American guidelines, only 10 of the 13 institutions indicated that they modified their administered activities according to the guidelines.
Educational Objectives

1. Understand the specific need for dose optimization in children
2. Become familiar with strategies and approaches for dose optimization in nuclear imaging
3. Become familiar with strategies and approaches for dose optimization in CT imaging
UNSCEAR 2008

- 3.6 billion x-ray examinations
- ≈180 million on children
- ≈18 million CT on children
Automatic Exposure Control (AEC)
Modulated mA values vs. kV
CT dose management

• Contrast enhancement? (Oral, type, IV?)
• Need pre-contrast scan
• Breath hold instructions?
• Acquisition parameters
  – Localizer [direction, technique, extent]
  – Helical/Axial scan
    – Bolus tracking, IV contrast delay, start/stop positions,
    – beam width (collimation), kV, rotation time, pitch, AEC
    – on/off + image quality reference parameter, image
    – thickness & recon filter, scan field of view
CT Dose management

• Reconstruction options
  – Algorithm/filter/kernel, iterative (strength), additional sets with different image thickness
  – Post-processing [reformatted sagittal/coronal, 3D, iterative reconstruction]
  – Misc.: image labels, exam splitting, physician check, instructions per sedative type or with vent tube in place
Tips for CT dose optimization

• Faster rotation time and higher pitch are often useful to reduce scan time
• But that requires high capacity x-ray tube for larger patients
• Pay attention to beam-on time, scan field of view, image thickness, IV contrast timing
• Implement noise reduction options when available (like iterative reconstruction)
• ACR CT Dose values for 1yr old head exam:
  • Ref. level CTDIvol = 35 mGy
  • Fail level CTDIvol = 40 mGy
DRLs for pediatric imaging

UPCOMING

• EC project PiDRL
• Through ICRP
Further Upcoming

• Are we giving the most appropriate radiation dose?
  – DRLs are based on practice “what is in use”
What is DRL?

Is that adequate?
Process of Optimization
Process of Optimization
Optimization

Does DRL do that?
Optimization

• In the absence of an Appropriate dose, there has been an erroneous tendency to assume that being below DRL means adequate optimization

• Most work (>90%) commenting that our results are within DRLs, many a times ignoring technology

• Is this Optimization or just one step in optimization?
• If DRL is just one step in optimization, what do we have for further optimization?
• Do we really have?
• Problem is not with DRL but stopping at DRL.
Limitations

• Not meant to be used for individual patient, whereas current need is for optimization of dose to an individual patient.

• Reflect upon facility and on outcomes from retrospective analysis, whereas optimization currently needs to deal with prospective situation of deciding right parameters to be used for a patient at hand.
Limitations of DRLs

• Most dose survey for DRL have assumed acceptable image quality rather than confirming and documenting it.
Suggested Approach

Acceptable Quality Dose (AQD)

• The imaging specialist provides image quality criteria
• Images are graded using criteria and pooled in different weight group
• Median values of dose will represent appropriate for images of adequate quality and this will be AQD
Benefits

• Image quality-Primary, Dose-Secondary
• Can cover all weight groups
• Can be applicable to optimization of individual
COMMENTARY

Limitations of diagnostic reference level (DRL) and introduction of acceptable quality dose (AQD)

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DOSE SURVEYS AND DRLs: CRITICAL LOOK AND WAY FORWARD

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Recap

• Are children more sensitive to radiation than adults?

• Multiple diagnostic examinations that provide compelling situations that cannot be ignored

• Optimization in nuclear imaging of children (EANM and North American & Results achieved)

• Optimization in CT dose

• AQD
Thank You

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