Assessment of doses to embryo and fetus - external dosimetry

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Effects of ionising radiation

Deterministic effects

- lethal effect (miscarriage)
- mental retardation
- malformation

Stochastic effects

- cancer
- leukemia
- hereditary effects
The safety of diagnostic imaging during pregnancy is a significant concern for all clinicians.

The number of radiological examinations performed in pregnant patients is constantly growing.

The X-ray examination rate in pregnant patients increased by 107%.
Justification principle

- Alternative non-ionising imaging modalities, such as ultrasound (US) and magnetic resonance imaging (MRI) can be suggested
- In some cases the radiological examinations are justified
  - Kidney stone (not visualized on US)
  - Trauma
- In some cases the pregnancy status is only discovered after x-ray examination

Transverse image of the female patients with 30 and 8 weeks of pregnancy underwent CT in emergency department of USZ
Conceptus dose assessment

1. Normalized standard dose values
2. Measurements
3. MC Simulations
Standard dose metrics

- **Radiography**
  - Entrance skin dose (ESD)
  - Air Kerma

- **Fluoroscopy**
  - Dose Area Product (DAP)
  - ESD

- **CT**
  - CTDI
Conceptus dose assessment

- ESD is the measure of the radiation dose that is absorbed (mGy) by the skin as it reaches the patient.

- ESD dose is a directly measurable quantity, often, measured using TLDs.

\[
ESD = Output \times \left(\frac{kV}{80}\right)^2 \times \left(\frac{100}{FSD}\right)^2 \times mAs \times BSF
\]

- Where Output – output mGy/mAs of the tube at 80 kV at the distance of 100 cm normalized by 10 mAs and BSF is a backscatter factor.

Fetal dose can be conservatively estimated as 0.15 times the entrance skin dose.
Conceptus dose assessment

- The normalized doses can be converted to a study-specific values by applying several correction factors
  - Parameters of the examination in the study (kV, gestation age of the patient)
  - Type of the examination
Conceptus dose assessment

Measurements

MC Simulations
Measurements

• Thermoluminescent dosimeters (TLD)
  
  ✓ most commonly used in medical dosimetry
  ✓ various shapes and sizes
  
  – Hardware is needed (oven, analyzer)
  – Time-consuming
Measurements

- Metal-oxide-semiconductor field-effect transistor (MOSFET) dosimeters
  - small size
  - provide direct and simultaneous dose readout
    - upper dose limit ~200 Gy
    - Artifact if used in patients
Measurements

- Patient -> Dose on the surface
- Anthropomorphic Phantoms
Anthropomorphic phantoms

- Simulate human body at various body sizes and ages
- Tissues formulated with polymers equivalent to soft tissue, bones, lungs etc
- Manufactured in ~2 cm thick sections with holes
- TLDs can be positioned in each slice
Anthropomorphic phantoms

- For 1\textsuperscript{st} trimester unmodified adult phantom can be used
- For 2\textsuperscript{nd} and 3\textsuperscript{rd} trimester phantom should be modified to account for pregnant anatomy

J. Damilakis, University of Crete
Images of gelatin boluses representing pregnancy at (b) 6 and (c) 9 months. White dots in images represent TLDs distributed in uterus. Saeed et al., 2021

Alderson RANDO phantom and a beach ball containing water. Matsunaga et al., 2017

! Measurements do not provide the dose to the exact patient / conceptus
Patients geometry is different from a standard anthropomorphic phantom
MC Simulations

- Computational method
- Considered to be the «new gold standard»
- 3 main components
  - Object/subject
  - X-ray source
  - Geometry
MC Simulations

- Computational method
- Considered to be the «new gold standard»
- 3 main components
  - ✓ Object/subject
  - ✓ X-ray source
  - ✓ Geometry
MC Simulations

- As an object one can either use phantom or patients images

by Jorge Borbinha
Topical Reviews

An exponential growth of computational phantom research in radiation protection, imaging, and radiotherapy: a review of the fifty-year history

X George Xu

Rensselaer Polytechnic Institute Troy, New York, USA
Computational phantoms

• Stylized Phantoms

• Organs are simulated using surfaces described by equations, such as cylinders, spheres and cones

• 1960 first-generation of stylized anthropomorphic phantoms Oak Ridge National Laboratory (ORNL)
Computational phantoms

- In 1995, Stabin and his colleagues at ORNL adapted adult female phantom to represent a woman at the 3, 6 and 9 month of pregnancy.
Computational phantoms

- Voxel phantoms
- Based on data obtained from real CT and MRI scans with segmented organ components

ICRP reference Male and Female

Helga, Donna, Irene

Zankl et al. GSF, Germany
Computational phantoms

• Comparison of stylized adult phantom (left) and VIP-Man phantom (reproduced with permission from Taylor and Francis, Xu et al 2000) (right)

• Such anatomical differences can influence the accuracy of radiation dose estimates
Computational phantoms

- Boundary representation phantoms (BREP)
- Designed by Non-Uniform Rational B-Spline (NURBS) method or mesh method
- Compared to the voxel phantoms, BREP phantoms are better suited for geometry deformation and adjustment

UF phantoms, SOLO

RPI phantoms
Patient Images

- DICOM images can be used as an input
  - Shape and position of the fetus
  - Maternal habitus

Transverse image of the female patients with 8 weeks of pregnancy
Transverse image of the female patients with 35 weeks of pregnancy
Patient Images

- Organs are not delineated
- No information outside of the scan FOV (cannot be used for estimations in chest CT)
- Not an option for fluoroscopy
MC Simulation

- 3 main components
  - Object/subject
  - X-ray source
  - Geometry
X-ray source

- Energy spectra
- mA and automatic exposure algorithm
- Filtration
X-ray source

- Fluroscopy
  - Pulse rate
  - Collimation

- CT
  - Focus
  - Total beam width
Geometry

• 3 main components
  ✓ Object/subject
  ✓ X-ray source
  ✓ Geometry
Geometry

- Fluoroscopy
  - Distance
  - Projection angles

- CT
  - Scan length
  - Trajectory (spiral vs sequential)
MC Simulation

- Computational Environment
- Monte Carlo N-Particle (MCNP) Transport Code
  - General purpose Monte Carlo radiation transport code that tracks all particles up to GeV range (n, e, γ)
  - generalized-geometry (all modalities)
MC Simulation

- PCXMC 2.0, STUK, Finnland
  - Program for calculating patients’ organ doses and effective doses in medical x-ray examinations (radiography and fluoroscopy)
  - adjustable-size paediatric and adult patient models
MC-based calculators

- ImPACT CT, UK
- Allows calculation of organ and effective doses to patients undergoing CT scans
- The ImPACT CTDosimetry spreadsheet + Monte Carlo data sets (NRPB SR250)
MC-based calculators

- ImPACT CT, UK
  - CT modality only
  - No specific dose estimations for pregnant patients i.e. conceptus
MC-based calculators

• Conceptus radiation doses and risks from imaging with ionizing radiation (CONCERT) - research project with the aim to optimize radiological procedures for pregnant women

• Develop a software expert system ['COnceptus Dose Estimation' (CODE)] that allows to calculate conceptus dose and risk from radiological procedures
  – patients
  – workers

http://embryodose.med.uoc.gr/
MC-based calculators

- CODE
- Web-based
- Free of Charge
  - User has to provide
    - CTDI free in air
    - beam collimation
    - CTDI normalized by 100mAs

http://embryodose.med.uoc.gr/
MC-based calculators

- Fetaldose.org
- Aim to create a tool for simple and accurate conceptus dose assessment from CT
- RPI phantoms representing female patients at 3, 6 and 9 month of pregnancy

Radiation Dose to the Fetus From Computed Tomography of Pregnant Patients—Development and Validation of a Web-Based Tool

Natalia Saltybaeva 1, Alexandra Platon 2, Pierre-Alexandre Poletti 2, Ricarda Hinzpeter 1, Marta Sans Merce 2, Hatem Alkadhi 1
MC-based calculators

- Web-based, free of charge, easy to use
- Validated
  - CT only

![Fetal Dose Calculator](fetaldose.org)

- **Gestational age, month**
  - 0-3

- **Tube voltage, kVp**
  - 100kVp

- **CTDvol, mGy**
  - 8

  Volume CT Dose Index obtained from patient radiation dose report.

- **Maternal perimeter, mm (optional)**
  - 1000

  Maternal perimeter in mm defined from the CT section containing the central area of the uterus.

- **Calculate**

- **Radiation dose to the fetus, mGy**: 9.03
Take Home Message

- X-ray based procedures during pregnancy represent significant concern for caregivers and patients
- Conceptus dose and risk from such procedures should be evaluated
- Normalized standard dose metrics, MC simulations or measurements can be used to evaluate the dose
- MC-based calculators are very helpful for fast and accurate assessment of the conceptus dose
Thank you for your attention!

EURADOS Working Group 12
Dosimetry in Medical Imaging
SG2/Task 4: «Dosimetry in pregnancy»