Cardiac and skin dose measurement using anthropomorphic phantoms for pediatric patients undergoing cardiac catheterization

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Duke University Medical Center
Background & Motivation
What is cardiac catheterization?

It is …

An invasive procedure that helps diagnose and non-surgically treat structural heart defects using specially designed cardiac catheters and implantable devices.
<table>
<thead>
<tr>
<th>Purposes of CC</th>
<th>Description</th>
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<tbody>
<tr>
<td>General Diagnosis</td>
<td>Checking of blood flow, valvular function and other defects</td>
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<tr>
<td>Biopsy</td>
<td>Removal of a cardiac muscle sample</td>
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<td>Valvuloplasty, or Balloon Valvulotomy</td>
<td>Widening of heart valve</td>
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<td>Angioplasty</td>
<td>Widening of vessel with balloon</td>
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<tr>
<td>Stent Implementation</td>
<td>Widening of vessel with stent</td>
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<td>Balloon and Blade Septostomy</td>
<td>Valve perforation</td>
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<tr>
<td>Valve</td>
<td>Opening of blocked pulmonary valve</td>
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<tr>
<td>Occlusion</td>
<td>Plugging up or closing of an unwanted opening</td>
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What is the relevant radiation concern in CC?

- Fluoroscopic x-ray imaging
- A large portion of patients are young children (w/ congenital health defects)
- Risk of skin injury, cancer, cardiac diseases
What are the challenges in pediatric patient dosimetry for CC?

1. Large variation in patient size

2. Large variation in imaging techniques and parameter settings

3. No fixed imaging protocol; mostly up to clinician practice.
For Allura Xper FD10/10 (Philips Healthcare), their Automatic Dose Rate Control (ADRC) is designed to balance the following factors:

Existing (mainstream) dosimetry research

• Mostly done by clinical groups that report procedural indices such as fluoro time, (air kerma) AK, (dose area product) DAP, etc.

• All of these quantities are indicators for how much radiation was applied during a procedure, but not so much for how much radiation dose a patient received – let alone organ-specific dose
To take things into a even broader prospective:

Far-future:
Quantitative, specific radiation-associated health risks

Near-future:
Patient-specific dose estimation for pediatric CC
Dissertation Title:
Patient Dose Estimation for Pediatric Patients Undergoing Cardiac Catheterization

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<td>Cardiac &amp; Skin</td>
<td>Whole-body organ</td>
<td>Procedure dose reconstruction and</td>
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<td>dependence</td>
<td>dose measurement</td>
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Project Overview

Dissertation Title:
Patient Dose Estimation for Pediatric Patients Undergoing Cardiac Catheterization

| Part I. MOSFET angular dependence | Part II. Cardiac & Skin dose measurement | Part III. Whole-body organ dose measurement & effective dose evaluations | Part IV. Procedure dose reconstruction and algorithmic dose estimation |
Scope of study

- Two age groups
  - Newborn
  - Five-year-old
- One imaging system
  - Allura Xper FD10/10
- Fluoro & Cine imaging
  - in 5 projection angles
  - Varying SID, Magnification & collimation

CIRS Atom-series phantoms
Scope of study

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Slab #7 - Newborn
Scope of study

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Slab #12 – 5yo
Scope of study

- Two age groups
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  - Five-year-old
- One imaging system
  - Allura Xper FD10/10
- Fluoro & Cine imaging
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Slab #13 – 5yo
Scope of study

- Two age groups
  - Newborn
  - Five-year-old
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  - Allura Xper FD10/10
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<th>Dosimeter Holes</th>
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<td>H10</td>
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<td>H11</td>
<td>Right Coronary Artery / Tricuspid Valve / Pulmonary Valve</td>
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<tr>
<td>H12</td>
<td>Circumflex Artery / Mitral Valve</td>
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<tr>
<td>H13</td>
<td>Distal RCA / Tricuspid Valve</td>
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<td>Left Anterior Descending Artery (LAD) / Interventricular Septum</td>
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Newborn, Fluoro

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Dosimeters

- **Cardiac:**
  High-sensitivity MOSFET (TN 1002RD-H)

- **Skin Entrance**
Dosimeters

- **Cardiac:**
  High-sensitivity MOSFET (TN 1002RD-H; Best Medical)

- **Skin Entrance**
  0.18cc ion chamber (Radcal)
Dosimeters

• Cardiac:
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• Skin Entrance
  0.18cc ion chamber (Radcal)
Results

Cardiac & Skin Dose Rates
Cardiac and Skin Entrance Dose Rates, Newborn Fluoro
Cardiac and Skin Entrance Dose Rates, Newborn Cine

- Cardiac
- Skin Entrance

![Bar chart showing organ dose rates for different cine scans with cardiac and skin entrance dose rates displayed.](chart_image)
Cardiac and Skin Entrance Dose Rates, Five-year-old Fluoro, At Various Dosimeter Locations

Organ Dose Rate, mGy/s

- Fluoro#1 PA
- Fluoro#2 LAT
- Fluoro#3 70/20
- Fluoro#4 20/15
- Fluoro#5 30 RAO
- Fluoro#6 High SID
- Fluoro#7 6"
- Fluoro#8 10"
- Fluoro#9 w/o coll.

Skin Entrance
Cardiac and Skin Entrance Dose Rates, Five-year-old Cine, at Various Dosimeter Locations

Organ Dose Rate, mGy/s

- Cine#1 PA 8" w/ coll.
- Cine#2 LAT
- Cine#3 70/20
- Cine#4 20/15
- Cine#5 30 RAO
- Cine#6 High SID
- Cine#7 6"
- Cine#8 10"
- Cine#9 w/o coll.
Results

System Indices (AK, DAP)

Vs.

Organ Dose Rates (Cardiac, Skin Entrance)
Newborn, vs. Skin Entrance

5yo, vs. Skin Entrance

Newborn, vs. Cardiac

5yo, vs. Cardiac
Newborn, vs. Skin Entrance

\[ y = 2.272x \]
\[ R^2 = 0.9355 \]

Newborn, vs. Cardiac

\[ y = 2.6363x \]
\[ R^2 = 0.7213 \]

5yo, vs. Skin Entrance

\[ y = 10.028x \]
\[ R^2 = 0.4550 \]

5yo, vs. Cardiac

\[ y = 10.028x \]
\[ R^2 = 0.4550 \]
Conclusion

• Measured dose rates for 5 common projection angles

• Obtained quantitative understanding of individual imaging parameter’s effect on patient dose rate

• System indices (AK & DAP) are too age- and protocol-specific to be good direct indicators for total procedural patient dose
Project Overview

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Many thanks to my colleagues at the Duke Radiation Dosimetry Laboratory (DRDL):

Giao Nguyen (Lab Manager)
Matthew Belley, Ph.D.
Natalie Januzis, M.S.
Bria Moore, B.S.
Justin Randabaugh, B.S.