Reduction of Radiation to Children:
Our Responsibility to Change

Running title: Andreassi et al.; Radiation exposure and CHD

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Medical radiation from X-rays and nuclear medicine is the largest man-made source of radiation exposure in Western countries, and accounts for a mean effective dose (ED) of 3.0 milliSievert (mSv) per person per year, equivalent to a radiation dose of 150 chest X-rays. In the USA, cardiologists are responsible for about 40% of the entire cumulative ED to the population from all sources, excluding radiotherapy.\textsuperscript{1} In pediatric patients with congenital heart disease (CHD), the annual ED is relatively low (< 3 mSv/year), but this extra yearly exposure accrues over the lifetime and can reach high values (> 100 mSv) in selected cohorts of pediatric chronic patients,\textsuperscript{2} especially those undergoing interventional fluoroscopy procedures and serial CT evaluations.\textsuperscript{3} The benefits of ionizing imaging in children, especially in those with CHD, are immense and often life-saving, even more so with the advent of invasive fluoroscopy and CT. Yet the use of radiation in children raises special concerns, and offers a unique challenge for the current generation of pediatric cardiologists.

The challenge of radiation damage in children

For any given radiological ED, younger pediatric patients receive higher radiation doses than older children, and overall, pediatric patients receive higher radiation doses than adult patients. Thus, the risk is three to four times higher in children than in adults.\textsuperscript{4} Children are at a substantially higher risk than adults because they have more rapidly dividing cells and greater life expectancy, allowing the clinical manifestation of radiation-induced cancers with decades-long latency periods,\textsuperscript{5} although this is more often true for some organs, such as the brain, and less for others, such as the lungs.\textsuperscript{6,7} At the age of 15-20 years, grown-up CHD patients have already accumulated an ED corresponding to 20-40 mSv, with an estimated lifetime attributable extra-risk of cancer of 1 in 10 to 1 in 100, with a detectable twofold increase compared to controls in chromosome aberrations,\textsuperscript{8} which are intermediate end-points and long-term predictors.
of cancer and appear soon after cardiac catheterization. Among pediatric patients with CHD, fluoroscopy-guided diagnosis and interventions account for 1.5 to 3.5% of all radiological examinations performed and 60 to 84% of their total collective dose. In the USA, the issue of radiological responsibility was addressed in the Image Gently, Step Lightly Campaign, focusing on the risks of unnecessary and excessive medical radiation exposure from interventional radiology administered to pediatric patients. A single invasive fluoroscopy procedure can reach values as high as 40 mSv per single procedure, especially if no systematic audit of dose is implemented in the cardiac cath lab. This is especially important in pediatric cardiology, since the increasing use and complexity of imaging and interventional techniques in pediatric patients has not been matched by increasing awareness and knowledge by prescribers and practitioners. Even in top-level pediatric cardiology centers, most interventional cardiologists and radiologists grossly underestimate the radiation doses for most commonly requested tests, and almost 50% of them ignore or deny that X-rays are a proven carcinogen.

The opportunity for better radiation protection in pediatric cardiology

As far as radiation damage is concerned, we should make every effort to bring the pediatric cardiology community from an evidence-poor to an evidence-rich milieu. Further data are needed, especially in the low-dose range (< 100 mSv). BEIR VII listed among top-research needs future medical imaging studies, including "studies of infants who experience diagnostic exposures related to cardiac cath". Similar studies have been performed on Australian or British cohorts of 120,000 and 680,000 children undergoing CT studies, and showed that a CT head scan increases the subsequent risk of brain cancer by 20%. A similar effort should be made by the pediatric cardiology community, and at least one nationwide study is currently underway to assess the long-term risk of cancer in children with CHD. Pediatric cohorts are
also ideally suited to identify the individual factors important in translating population into individual risk (Figure 1) and to assess other major non-cancer effects of radiation exposure, including atherosclerosis, brain aging, and reproductive effects.

**The governance of radiological responsibility: the 4 A’s approach**

Today, it is possible for a child with heart disease to be admitted to a tertiary care referral center and be cared for by a cardiologist, invasive cardiologist or cardiac radiologist who is unaware of the dose (s)he administers to the patient. The child can be given a dose that is tenfold higher than the reference dose and this dose is not reported anywhere in paper or digital records. The dose is not mentioned anywhere in the informed consent, although the risks can be as high as 1 in 100 per test. Even worse, the patient can be admitted to an institution run with public money where all imagers are encouraged to do more exams, especially with more costly techniques such as CT or invasive cardiology. In this cultural and economic milieu, "pay per volume" is the rule and implementing appropriateness and optimization in your laboratory can be dangerous for your professional survival. This praxis can no longer be accepted, and we need to have more efficient tools than “moral suasion” to force cardiologists to comply with high safety standards. In practice, this is best obtained through a systematic implementation of the 3A’s strategy proposed by the International Atomic Energy Agency (IAEA) in 2012 -- Awareness (since knowledge of doses and risks is still largely suboptimal in doctors and patients, but you have to know what you are going to do in terms of reference dose); Appropriateness (since at least one-third of examinations are inappropriate) and Audit (of true delivered dose, since you need to know what you have done, and the dose should be written down in the electronic records). To this 3A’s approach proposed by IAEA, a fourth one should probably be added: A for Accountability. The radioprotection aspect is vital for the health of our children and should be
safeguarded by political governance and verification of radiological activity. At present, in the words of Eric J. Topol, “we have a very important problem here with this runaway use of radiation procedures but no accountability with respect to patients’ exposure. (...) So, why don’t we tell patients when they have a particular imaging scan how many mSv they’re getting exposed to? (...) This is a serious breach of our responsibility to patients. In a digital world, this information could be collected from birth. Hopefully, we will see that change come about in the future, this is something that’s a big hole in the way we work in medicine”. The radiation issue is no longer a hidden variable ignored by doctors and patients, but a key factor in determining the rating of our pediatric cardiology division, the risk-benefit assessment of competing diagnostic and therapeutic options, the direction of future research, and the commercial success of new radiation-sparing technologies.

Take-home message

The interesting data of Johnson et al. further reinforce the clinical message of the recent ESC position paper on medical radiation, which holds true even more for pediatric cardiologists: "X-rays and γ-rays used in radiology and nuclear medicine are proven (class I) carcinogens and cardiologists should make every effort to give the right imaging exam, with the right dose, to the right patient. The priority given to radioprotection in every cardiology department is an effective strategy for primary prevention of cancer, a strong indicator of the quality of the cardiology division, and the most effective shielding to enhance the safety of patients, doctors and staff. A smart cardiologist cannot be afraid of the essential and often life-saving use of medical radiation, but must be very afraid of radiation unawareness".

According to the European Society of Radiology, the expected scenario in the coming years will allow better protection of patients (and staff) through appropriateness, optimization
actions through technological improvements, dose recording and dose management through Dose Reference Levels, and dedicated radiation protection training with certification (also for cardiologists). Pediatric cardiology should ideally be the first and most important stage to deploy in the field of this global approach to radiation protection.

In few fields of medicine can you obtain so much (in terms of improved quality of care of our patients) with so little (simply through increased knowledge of radioprotection essentials). You add awareness to the health care system, and you obtain safety. You inject responsibility and you gain primary prevention of cancer. It is time to abandon old, time-honored practices of radiological unawareness and enter a new era of radiological responsibility, full of opportunities for patients, doctors, and scientists (Table 1). CT and invasive fluoroscopy in children are essential tools for pediatric cardiologists – but they must be used prudently and optimally. Fifty years ago, a pioneer in the field of pediatric cardiology, Forrest H. Adams, wrote an editorial in Circulation on “Reduction of radiation to children” and he stated that “Properly controlled radiation can provide benefits that greatly outweigh the potential hazards if there are adequate indications for its use and the instrumentation and technics are optimal. (...) Ideally, radiation exposure records should be maintained for each patient, particularly those requiring long-term follow-up”. Half a century later, we have to more or less repeat his own words. Only after that game-changing reshaping of our cardio-radiological practice will pediatric cardiologists be entitled to repeat the words of JFK: "We can say with some assurance that, although children may be the victims of fate, they will not be the victims of our neglect".

Conflict of Interest Disclosures: None.
References:


Table 1. Radiation in pediatric cardiology: our responsibility to change.

<table>
<thead>
<tr>
<th>PATIENT</th>
<th>What we have</th>
<th>What we need</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominant culture</td>
<td>More (exams) is better</td>
<td>Less (dose) is better</td>
</tr>
<tr>
<td>Recordkeeping</td>
<td>Number of tests</td>
<td>Dose of each test</td>
</tr>
<tr>
<td>Radiation history</td>
<td>Absent</td>
<td>Present</td>
</tr>
<tr>
<td>Radiological informed consent</td>
<td>Absent</td>
<td>Informative</td>
</tr>
<tr>
<td>Received dose in report</td>
<td>Missing</td>
<td>Mandatory</td>
</tr>
<tr>
<td>Dose coding</td>
<td>Fluoroscopy time</td>
<td>ED, KAP or DAP</td>
</tr>
<tr>
<td>Organ Dose</td>
<td>Ignored</td>
<td>Considered</td>
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</tbody>
</table>

<table>
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<th>DOCTOR</th>
<th>What we have</th>
<th>What we need</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology upgrading</td>
<td>More short-term cost</td>
<td>Less long-term risk</td>
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<tr>
<td>Lowering dose</td>
<td>A curiosity for physicist</td>
<td>Preventing cancer</td>
</tr>
<tr>
<td>The cancer risk</td>
<td>Theoretical</td>
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<tr>
<td>What can protection do</td>
<td>Reduce work comfort</td>
<td>Allow to live longer</td>
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<tr>
<td>Dose reading</td>
<td>Off-line, months after</td>
<td>On-line, real time</td>
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</table>

<table>
<thead>
<tr>
<th>SCIENTIST</th>
<th>What we have</th>
<th>What we need</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiological risk estimation</td>
<td>Population-based</td>
<td>Personalized</td>
</tr>
<tr>
<td>Epidemiological data on staff</td>
<td>Nuclear power plant workers</td>
<td>Cardiac cath lab workers</td>
</tr>
<tr>
<td>Epidemiological data on pts</td>
<td>Children with CT</td>
<td>CHD patients</td>
</tr>
<tr>
<td>Focus on risks</td>
<td>Only cancer risks</td>
<td>Non-cancer risks</td>
</tr>
</tbody>
</table>

CHD = congenital heart disease; CT = Computed Tomography; DAP = Dose Area Product; ED = Effective Dose; KAP = Kerma Area Product

Figure Legend:

Figure 1. The physical dose can be effectively reduced with a systematic approach of appropriateness (justification) of exams and dose audit leading to optimization. This will determine an overall reduction in the dose level (white beam). The physical dose is linearly related to population risk, but true individual risk can be better identified when the monochromatic light of the physical dose is split into a spectrum of individual risk considering age, gender, genes, environmental co-factors and co-morbidities. The risks include not only cancer but likely also non-cancer risks.
DOSE

Higher
Unjustified
Unoptimized
Justified
Optimized

Lower

RISKS
(cancer and non-cancer)

Higher

Children
Females
Vulnerable genotypes

Resistant genotypes
Males
Elderly

Lower
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