Radiation in cardiology: use it wisely!

How to optimize diagnostic and therapeutic procedures for maximum patient safety

Eugenio Picano, MD, PhD

Institute of Clinical Physiology, Pisa, Italy

NO CONFLICTS OF INTERESTS TO DISCLOSE
“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 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, will see that change come about in the future, this is something that’s a big hole in the way we work in medicine”

*December 17, 2012*
Survey: Which is the dose of MPI?

- 49% Correct
- 29% Mild
- 13% Moderate
- 9% Severe

Legend:
- Correct
- Mild
- Moderate
- Severe

MISTAKE

1/2 chest X-ray
1 chest X-ray
3 chest X-ray
500 chest X-ray

Correia, Picano. Int J Cardiol 2005
Trust me, I’m the expert!
Radiologic daltonism

20% says CMR is ionizing

10% believes ultrasound are ionizing radiation

Shiralkar S et al, BMJ 2003

4% thinks ultrasound are ionizing

12% think scintigraphy is non-ionizing


Internist

Paediatrician
DESPITE great strides in prevention and treatment, cancer rates remain stubbornly high and may soon surpass heart disease as the leading cause of death in the United States. Increasingly, we and many other experts believe that an important culprit may be our own medical practices: We are silently irradiating ourselves to death.

The use of medical imaging with high-dose radiation — CT scans in particular — has soared in the last 20 years. Our resulting exposure to medical radiation has increased more than sixfold between the 1980s and 2006, according to the National Council on Radiation Protection & Measurements. The radiation doses of CT scans (a series of X-ray images from multiple angles) are 100 to 1,000 times higher than conventional X-rays.

Of course, early diagnosis thanks to medical imaging can be lifesaving. But there is distressingly little evidence of
CT risk for hermaphrodite aliens

“Calculations are based on standard hermaphrodite adult with a weight of 71 kg and height of 174 cm. For each modality, a comparable calculation technique was used, based on Montecarlo modeling of the standard Cristy phantom. The mean effective dose was 14.7 mSv”

J Am Coll Cardiol 2006; 47:1840-5
“Medical writing is a highly skilled, calculated attempt to confuse the reader”
(N Engl J Med 1975; 293:1257-9)
Stochastic risk cancer (take now, pay later)

Deposit of energy
Excitation/Ionization
Excitation of particles

Formation of free radicals
Diffusion, chemical reactions
Initial DNA damage

DNA damage
Repair mechanisms
Fixed damage

Cellular death
Mutations/transformations/aberrations

Cell proliferation
Promotion/completion

TERATOGENESIS
CANCER
HERITABLE DEFECTS

Scoliosis at age 9, breast cancer at age 40

Congenital heart disease at age 1, leukemia or lung cancer at age 30

Head Ct at age 5, brain cancer at age 50

United Nations UNSCEAR 2001
Radiation in cardiology

- Doses to patients
- Risks to patients
- Doses and risks to doctors
- Radiotherapy
- Public health perspective
## Table 4  Conversion factors: from jargon to effective dose

<table>
<thead>
<tr>
<th>CT</th>
<th>Conversion factor</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLP (for chest)</td>
<td>mSv = DLP (mGy × cm) × 0.021</td>
<td>Christner et al.</td>
</tr>
<tr>
<td>DLP (for coronary arteries)</td>
<td>mSv = DLP (mGy × cm) × 0.030</td>
<td>Geleijns et al.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Radiology</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>KAP in adults</td>
<td>mSv = KAP (Gy cm²) × 0.2</td>
<td>Rehani</td>
</tr>
<tr>
<td>KAP in 15 year olds</td>
<td>mSv = KAP (Gy cm²) × 0.4</td>
<td>Karambatsakidou et al.</td>
</tr>
<tr>
<td>KAP in 5 year olds</td>
<td>mSv = KAP (Gy cm²) × 1.0</td>
<td>Karambatsakidou et al.</td>
</tr>
<tr>
<td>KAP in &lt;1 year olds</td>
<td>mSv = KAP (Gy cm²) × 1.9</td>
<td>Karambatsakidou et al.</td>
</tr>
<tr>
<td>KAP in newborns</td>
<td>mSv = KAP (Gy cm²) × 3.7</td>
<td>Karambatsakidou et al.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nuclear cardiology</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SPECT $^{99m}$Tc–sestamibi (rest)</td>
<td>mSv = MBq × 0.0092</td>
<td>Einstein et al.</td>
</tr>
<tr>
<td>SPECT $^{99m}$Tc–sestamibi (stress)</td>
<td>mSv = MBq × 0.0078</td>
<td>Einstein et al.</td>
</tr>
<tr>
<td>SPECT $^{99m}$Tc–tetrofosmin (rest)</td>
<td>mSv = MBq × 0.0073</td>
<td>Einstein et al.</td>
</tr>
<tr>
<td>SPECT $^{99m}$Tc–tetrofosmin (stress)</td>
<td>mSv = MBq × 0.0065</td>
<td>Einstein et al.</td>
</tr>
<tr>
<td>SPECT $^{201}$TI (stress-redistribution)</td>
<td>mSv = MBq × 0.22</td>
<td>Gaemperli et al.</td>
</tr>
<tr>
<td>PET $^{13}$N-ammonia (stress–rest)</td>
<td>mSv = MBq × 0.0022</td>
<td>Gaemperli et al.</td>
</tr>
<tr>
<td>PET $^{15}$O–H$_2$O (stress–rest)</td>
<td>mSv = MBq × 0.0011</td>
<td>Gaemperli et al.</td>
</tr>
<tr>
<td>PET $^{82}$Rb (stress–rest)</td>
<td>mSv = MBq × 0.0036</td>
<td>Gaemperli et al.</td>
</tr>
<tr>
<td>PET $^{18}$F–FDG (rest)</td>
<td>mSv = MBq × 0.0189</td>
<td>Gaemperli et al.</td>
</tr>
</tbody>
</table>

CT, computed tomography; KAP, kema-area product; DLP, dose-length product; PET, positron-emission tomography; SPECT, single-photon emission computed tomography.
“For the assessment of appropriateness, negative consequences include the risk of the procedure itself (i.e., radiation or contrast exposure)”  
*Patel et al, JACC 2005*
# Invasive Fluoroscopy - ADULT

<table>
<thead>
<tr>
<th>Diagnostic procedures</th>
<th>Effective dose (mSv)</th>
<th>Equivalent CXRs</th>
<th>Background radiation (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnostic coronary angiography</td>
<td>7 (2-16)</td>
<td>350</td>
<td>2.9</td>
</tr>
<tr>
<td>Percutaneous coronary Intervention</td>
<td>15 (7-57)</td>
<td>750</td>
<td>6.3</td>
</tr>
<tr>
<td>Thoracic angiography (pulmonary or aorta)</td>
<td>5 (4-9)</td>
<td>250</td>
<td>2.1</td>
</tr>
<tr>
<td>Abdominal angiography or aortography</td>
<td>12 (4-48)</td>
<td>600</td>
<td>5.0</td>
</tr>
<tr>
<td>Pelvic vein embolization</td>
<td>60 (44-78)</td>
<td>3000</td>
<td>25.0</td>
</tr>
<tr>
<td>TIPS placement</td>
<td>70 (20-180)</td>
<td>3500</td>
<td>29.3</td>
</tr>
<tr>
<td>Aortic valvuloplasty</td>
<td>39 (12-100)*</td>
<td>1950 (600-5,000)*</td>
<td>16.2 (5-41)*</td>
</tr>
<tr>
<td>Dilation chronic coronary occlusion</td>
<td>81 (17-194)</td>
<td>4050</td>
<td>33.7</td>
</tr>
<tr>
<td>ETAAAR procedure</td>
<td>76-119</td>
<td>3800-5950</td>
<td>31.6-49.5</td>
</tr>
<tr>
<td>Renal angioplasty</td>
<td>54</td>
<td>2700</td>
<td>22.5</td>
</tr>
<tr>
<td>Iliac angioplasty</td>
<td>58</td>
<td>2900</td>
<td>24.1</td>
</tr>
</tbody>
</table>

ETAAAR = Endovascular Thoraco Abdominal Aortic Aneurysm Repair

*ACC position paper 2018, Hirschfeld et al, JACC
Invasive Fluoroscopy – PAEDIATRIC

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</tr>
</thead>
<tbody>
<tr>
<td>Diagnostic cardiac catheterization</td>
<td>6.0 (0.6-23.2)</td>
<td>Age-dependent</td>
<td>2.5</td>
</tr>
<tr>
<td>Closure of Atrial Septal Defect</td>
<td>2.8 (1.8-7.4)</td>
<td>Age-dependent</td>
<td>1.1</td>
</tr>
<tr>
<td>Patent ductus arteriosus occlusion</td>
<td>7.6 (2.1-37)</td>
<td>Age-dependent</td>
<td>3.2</td>
</tr>
<tr>
<td>Balloon valvuloplasty</td>
<td>8.1 (2.9-20)</td>
<td>Age-dependent</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Fluoroscopically guided procedures account, on average, for more cumulative ionizing radiation to children with congenital heart disease than all other medical imaging modalities combined. It is now incumbent on the imaging community to ensure that these procedures are optimized to ensure image quality appropriate to the medical needs of the patient but at the lowest achievable dose (Hill KD et al, IMAGE GENTLY ALLIANCE, JACC CV imaging 2017)

Picano E et al Position paper 2014

*ACC position paper 2018, Hirschfeld et al, JACC
Standard average reference doses of common cardiological examination

**Cardiac Electrophysiology**

<table>
<thead>
<tr>
<th>Diagnostic procedures</th>
<th>Effective dose (mSv)</th>
<th>Equivalent CXRs</th>
<th>Background radiation (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnostic EP studies</td>
<td>3.2 (1.3-23.9) 0.1-3.2*</td>
<td>160</td>
<td>1.2</td>
</tr>
<tr>
<td>Ablation procedure:</td>
<td>15.2 (1.6-59.6) 1-25*</td>
<td>760</td>
<td>5.7</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>16.6 (6.6-59.2)</td>
<td>830</td>
<td>6.9</td>
</tr>
<tr>
<td>AT-AVNRT-AVRT</td>
<td>4.4 (1.6-25)</td>
<td>220</td>
<td>1.8</td>
</tr>
<tr>
<td>Ventricular Tachycardia</td>
<td>12.5 (3-45)</td>
<td>625</td>
<td>5.2</td>
</tr>
<tr>
<td>Regular PM or ICD implant</td>
<td>4 (1.4-17) 0.2-8.0*</td>
<td>200</td>
<td>1.6</td>
</tr>
<tr>
<td>CRT implant</td>
<td>22 (2.2-95)</td>
<td>1100</td>
<td>9.1</td>
</tr>
</tbody>
</table>

AT = Atrial Tachycardia; AVRT = Atrio-Ventricular Reciprocal Tachycardia; CXRs = Chest X-Rays; CRT = Cardiac Resynchronization Therapy;

* ACC position paper part 1, Hierschfeld J W et al, JACC 2018, part 1
Standard average reference doses of common cardiological examination CT

<table>
<thead>
<tr>
<th>Diagnostic procedures</th>
<th>Effective dose (mSv)</th>
<th>Equivalent CXRs</th>
<th>Background radiation (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>64-slice coronary CTA</td>
<td>15 (3-32)</td>
<td>750 (150-1,600)</td>
<td>6.25</td>
</tr>
<tr>
<td>Calcium score</td>
<td>3 (1-12)</td>
<td>150</td>
<td>1.25</td>
</tr>
</tbody>
</table>

Picano E et al, EHJ Position paper 2014
<table>
<thead>
<tr>
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<th>Effective dose (mSv)</th>
<th>Equivalent CXRs</th>
<th>Background radiation (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET F-18 FDG rest (400 MBq, viability)</td>
<td>8</td>
<td>400</td>
<td>3.3</td>
</tr>
<tr>
<td>PET Rubidium-82 stress-rest (3700 MBq)</td>
<td>4.6</td>
<td>230</td>
<td>1.9</td>
</tr>
<tr>
<td>PET N-13 ammonia stress-rest (1100 MBq)</td>
<td>2.4</td>
<td>120</td>
<td>1</td>
</tr>
<tr>
<td>PET $^{15}$O-H$_2$O stress-rest (2200 MBq)</td>
<td>2.5</td>
<td>125</td>
<td>1.04</td>
</tr>
<tr>
<td>$^{99m}$Tc-lab erythr (1110 MBq, cardiac function)</td>
<td>7.8</td>
<td>390</td>
<td>3.25</td>
</tr>
<tr>
<td>SPECT-$^{201}$TI stress/redistr. (130 MBq, sing inj)</td>
<td>22</td>
<td>1100</td>
<td>91.6</td>
</tr>
<tr>
<td>$^{201}$TI stress/rest reinj. (185 MBq, double inj)</td>
<td>40.7</td>
<td>2035</td>
<td>16.9</td>
</tr>
<tr>
<td>$^{99m}$Tc -Sestamibi (1100 MBq, 1 day) stress-rest</td>
<td>9.4</td>
<td>470</td>
<td>3.9</td>
</tr>
<tr>
<td>$^{99m}$Tc-Tetrofosmin (1500 MBq, 1 day) stress-rest</td>
<td>11.4</td>
<td>570</td>
<td>4.7</td>
</tr>
</tbody>
</table>

Standard average reference doses of common cardiological examination: Nuclear Cardiology

Picano E et al, EHJ Position paper 2014
Cumulative radiation exposure per patient

Non IHD patients

IHD patients

Mean mSv per patient

1970-1974
1985-1990
2005-2009

1970-1974
1985-1990
2005-2009

Interv Cardiology

Nuclear cardiology

Carpeggiani C et al, PLOSOne, 2012
The Ulysses syndrome of Homer

Consider Jim, a 58-year old man with newly diagnosed angina pectoris. (...) By referring Jim to 3 common outpatient imaging tests (exercise myocardial perfusion scan, CT scan, invasive coronary angiography), his physician inflicted at least 2 harms. First, Jim incurred in costs for procedures of uncertain value. Second, Jim was exposed to radiation.

Despite these harms, our medical system sees nothing wrong with Jim’s care.

(Lauer MS, 2009;361:841-3)
Serial Stress testing: Mururoa man walking

1. Primary diagnosis
2. Therapy effect
3. CAD progression
4. Pre and post-PCI
5. Risk stratification
“Imaging procedures are an important source of exposure to ionizing radiation in the United States and can result in high cumulative effective doses of radiation.”
Radiation in cardiology

- Doses to patients

- **Risks to patients**

- Doses and risks to doctors

- Radiotherapy

- Public health perspective
• X-rays and gamma-rays are a proven carcinogen (WHO’s International Agency of Research on Cancer)
• Risk estimates are not, and can never be, a direct measurement
• Estimates, not fears – based on 100,000 + studies, including 87,000 Hiroshima and 407,000 nuclear workers
• 2 to 3 Confidence Intervals of attributable risks estimate
• Radiation cancer risks somewhat higher than prior estimate (BEIR V, ICRP 1990)
• Epidemiological evidence now above 50 mSv
Informed consent and communication of risk from radiological and nuclear medicine examinations: how to escape from a communication inferno

Eugenio Picano

Radiological and nuclear medicine examinations confer a definite (albeit low) long term risk of cancer, but patients undergoing such examinations often receive no or inaccurate information about these risks. Picano argues that this disregard of patient autonomy is no longer acceptable and suggests a practical way of communicating risk.

Dante Inferno, Canto IX, 61-64

Oh you possessed of sturdy intellects,
Observe the teaching that is hidden here,
Beneath the veil of verses so obscure

You cannot explain to the patient the radiation risk if you are not aware of it.
Dose can be easily communicated with multiple of chest x-rays (the euro of radiation dose)
Risk of cancer (fatal and non-fatal) for exposure to one 64-slice coro-CT
Elderly: 1 in 1,500
Adult man: 1 in 750
Adult woman: 1 in 500
Male child (<1 year): 1 in 200
Female child (<1 year): 1 in 100
## Imaging and extra-risk of cancer

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Effective dose (milliSievert)</th>
<th>Risk of cancer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest x-ray</td>
<td>0.01</td>
<td>Negligible</td>
</tr>
<tr>
<td>Skull x-ray</td>
<td>0.1</td>
<td>Minimal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 in 1,000,000 to 1 in 100,000</td>
</tr>
<tr>
<td>Mammography</td>
<td>1.0</td>
<td>Very low</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 in 100,000 to 1 in 10,000</td>
</tr>
<tr>
<td>Cardiac scintigraphy</td>
<td>10</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 in 10,000 to 1 in 1,000</td>
</tr>
</tbody>
</table>

Tissue weighing factors from ICRP 2007

What one might expect:
Cancer risk = Organ dose x Radiosensitivity

(Ho et al: Cancer in interventional cardiologists 2016 Eur J Clin Invest, 542 cardiologists)*
The main limitation for CCT remains the use of ionizing radiation, which is an important consideration for all CHD patients requiring serial diagnostic imaging over a lifetime (Sachdeva et al, ACC-AHA Appropriate use criteria for imaging in Congenital heart disease, JACC January 1, 2020)
Cancer in Congenital heart disease

24,833 adult CHD patients with 250,791 person-years of follow-up
(OR 1.10 per procedure and 3.08 for ≥ 6 procedures)

The excess cancer risk involved highly radiosensitive organs (red bone marrow and leukemia, lung, stomach, esophagus and female breast) that receive the highest organ dose from invasive cardiology testing

4-fold increased cancer risk in 2,770 pts with cardiac cath between 1980-98 at < 1 year (Stern H et al, JCM 2020)
42 spontaneous cancers

100 mSv for 100 patients

+ 1, Radiation induced

(1 in 100)

Risk estimates increased by 30 % by WHO 2013 and German SSK 2014 who abandoned DDRF (1.5 in BEIR VII and ICRP 2007)

Range of uncertainty

(1 in 30 – 1 in 300)

BEIR VII, 2006
Radiation in cardiology

• Doses to patients

• Risks to patients

• Doses and risks to doctors

• Radiotherapy

• Public health perspective
Radiomachismo

“Increasingly, we have become causal regarding our exposure. We forget to wear the dosimeters. Not infrequently, there is a machismo disregard for radiation protection”

Rita Watson, Sayonara ALARA, Cath Cardiov Diagn, 1997

REVISED GENEVA DECLARATION 2017 (the new Hippocratic Oath from World Medical Association):

I WILL ATTEND TO MY OWN HEALTH, WELL-BEING, and ABILITIES IN ORDER TO PROVIDE CARE OF THE HIGHEST STANDARD
“Friendly fire” on interventional cardiologists

- “If some precautions are not taken, radiologists will soon go to disaster “ (The New York Times, 1921: Professional ICRP limit 1931: 500 mSv /yr).

- “Exposure of interventional radiologists is above and beyond every regulatory support” (DIMOND EU Conc Action, 2001: Professional ICRP limit: 20 mSv/year)

Vano E et al, BJR 1998
Keep calm and protect! (shield, radiation, distance and... culture)

Radio-macho man, sayonara ALARA!
(Rita Watson, Cath Card Diagn, 1997)

Cumulative dose and Cancer (and non-cancer) risk

Baseline risk

GOOD RADIOPROTECTION HABIT

BAD RADIOPROTECTION HABIT

Years of busy EP cath lab life

20 years of work, 100 mSv exposure, 1 extra-cancer in 100 exposed subjects
Cath lab: we don’t need another hero

A reduction of the effective dose by a factor of 10 has been achieved. The most successful action to reduce occupational doses has been training in radiation protection.

Vano E et al, Br J Radiol 2006
Reduction of radiation delivered to patients undergoing invasive coronary procedures. Effect of a programme for dose reduction based on radiation-protection training.

- 2 day training course
- Routine left ventriculography discouraged
- Low fluoroscopic pulse rate
- Etc…

Training in radiation was associated with a 50% reduction in radiation exposure to patients undergoing invasive cardiac procedures, without any loss of diagnostic information.
HEALTHY CATH LAB

EP and Invasive cardiologists meet molecular epidemiology


Andreassi MG et al.
FASEB J 2005

G. Guagliumi
R. Padovani
M. Del Greco
F. Gaita

E. Piccaluga
M. Ostojic
E. Picano

Picano E et al, ESC position paper, Eur Heart J 2014

M. Del Greco
F. Gaita

ANMCO Seminal grant for best ethical project 2006 (90.000 euros)

“IT would be impossible to do this research without or against the invasive cardiologists or the interventional radiologist”
The radiosensitivity of a tissue depends on the number of undifferentiated cells in the tissue, their mitotic activity, and the length of time they are actively proliferating.

Heart and Brain, the MYTH of radioresistant organs
Brain tumor in the cath lab

“The left side is the side usually exposed to more radiation. Of legal importance, recently, the brain tumor of one physician was recognized by the legal authorities in his country as a professional disease related to his work and exposure to radiation in the catheterization laboratory”

Roguin A. Radiation in cardiology: can’t live without it! Eur Heart J 2014; 35: 599-600
HCL : mind the Brain!

**The background evidence:**
- Chronic low dose IR (0.3 Sv) induces Alzheimer-like changes in rat brain *(Kempf SJ, 2016)*
- Brain dose without protection may reach 2-4 Sv on left hemisphere *(Picano E, 2012)*
- Memory abnormalities 10-fold more prevalent (12%) in HCL *(Marazziti D, HCL, JNPS, 2015)*
- Olfactory abnormalities 3-fold more prevalent (18%) in HCL *(Tonacci A and HCL, IntJC 2014)*
- Anxiety-depression 6-fold more prevalent *(Andreassi MG et al, HCL survey, Circ Int, 2016)*
- Simple cap protection reduces exposure by 99% *(Reeves RR et al, JACC int 2015)*

*(Borghini A, Andreassi MG, Picano E et al, CIRCULATION October 2017)*
HCL: mind the eye!

The background evidence:
- Eye dose without protection: 113 (19-800) µSv per procedure (Kim KP, 2012)
- Posterior Cataract 5.7-fold more prevalent (50%) in IC (Ciraj-Bjelac, 2010)
- ICRP slashed annual eye dose limit from 150 to 20 mSv/year (ICRP 2011)
- Diabetes associated with 20-fold increased risk of cataract (Little W. December 2, 2019, Occup Env Med)
- 5 excess cases per 1,000 persons exposed to 50 mGy and followed over 10 years
HCL: mind the Brain!

The background evidence:
- Chronic low dose IR (0.3 Sv) induces Alzheimer-like changes in rat brain (Kempf SJ, 2016)
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- Simple cap protection reduces exposure by 99% (Reeves RR et al, JACC int 2015)
HCL: mind the vessel!

Andreassi MG, Piccaluga E, Guagliumi G, Picano E et al. *JACC int 2015*

The background evidence:
- Dose to neck can reach 2 Sv in the cath lab lifetime (*Vano et al, 1998*)
- Ionizing radiation triggers activation of the endothelium (*Cervelli T, Atherosc 2014*)
- Radiotherapy is a powerful pro-atherosclerotic agent (*Darby S et al, NEJM 2013*)
- Meta-analysis links low dose to CV events, similar to cancer risk (*Little 2012*)
Reproduction: physiology and anecdotes

90 exposed and
90 non-exposed physicians

Legal exposure limits for pregnant mothers in cath lab:
5 mSv in the USA
1 mSv in the EU
The background evidence:

- Dose-related effect from 150 mSv on human sperm (Rowley et al, 1974)
- Male gonadal dose twice higher than female gonadal dose (Theocaropoulos 2006)
- Father exposure x3-times the risk of sporadic bilateral retinoblastoma in child (Bunin 2011)
- Exposed workers with worse semen quality and more DNA damage (Kamar 2013)
- In utero exposure (>0.1 Gy) between weeks 5 to 15 increases risk of seizures (Dunn 1999)
Reproductive Outcomes and Y Chromosome Instability in Radiation-Exposed Male Workers in Cardiac Catheterization Laboratory

(Andreassi MG, Picano E et al, Env Mol Mutagenesis 2020)
HEALTHY CATH LAB

EP and Invasive cardiologists meet molecular epidemiology


Andreassi MG et al. FASEB J 2005
Andreassi MG et al. Eur Heart J 2006
Andreassi MG et al, JACC int 2015; Circ Interv 2016; Circulation 2017; EJ Prev med 2020

ANMCO Seminal grant for best ethical project 2006 (90.000 euros)

Picano E et al, ESC position paper, Eur Heart J 2014

Picano E, BMJ 2004

“It would be impossible to do this research without or against the invasive cardiologists or the interventional radiologist”
Responsibility in the cath lab

Responsibility on all physicians to minimize the radiation injury hazard to their patients, to their professional staff, and to **themselves**

Hirschfeld JW et al, ACC/AHA Guidelines, Circulation 2005
<table>
<thead>
<tr>
<th>Main funding</th>
<th>NIH and NCI</th>
<th>Italian CNR National Research Council – IFC, Institute of Clinical Physiology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific Societies endorsement</td>
<td>Multispecialty Occupational Health Group</td>
<td>Italian Society of Invasive Cardiology (GISE)</td>
</tr>
</tbody>
</table>
| Enrolled population              | • 44,000 fluoroscopists (interventional cardiologists, radiologists, neuroradiologists)  
|                                  | • 49,000 non-interventional radiologists                                    | • 500 exposed interventional cardiologists (nurses, technicians)        |
|                                  | • 100,000 non-exposed physicians                                            | • 500 non exposed clinical cardiologists (nurses, technicians)           |
| Endpoint                         | Epidemiological clinical endpoints (cancer, cataract, vascular events)     | Surrogate biomarkers of genetic, vascular, reproductive, neurocognitive effect |
Robocath raises 7-million to market its first medical robotic platform in 2018 (marketed in February 2019)
Next stop: EU HARMONICS trial in cardiac patients treated as children (6 million euros from Horizon 2020, started 2019 until 2024, coordinated by E.Cardis, Barcelona)
Radiation in cardiology

• Doses to patients

• Risks to patients

• Doses and risks to doctors

• Radiotherapy

• Public health perspective
Radiation-induced CVD
Major cause of morbidity and mortality in cancer survivors

Radioresistant organ
Postmitotic cardiac myocytes and extremely low proliferative activity of the endothelial cells and connective tissue cells

High dose ≥ 40 Sv
The estimated aggregate incidence of RIHD is **10-30 % by 5-10 years post-treatment**. Among these patients who received radiation, cardiovascular disease is the most common non-malignant cause of death.

(Lancellotti P et al, Expert Consensus on RIHD, EHJ 2013)

**Table 2  Risk factors of radiation-induced heart disease**

<table>
<thead>
<tr>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior or left chest irradiation location</td>
</tr>
<tr>
<td>High cumulative dose of radiation (&gt;30 Gy)</td>
</tr>
<tr>
<td>Younger patients (&lt;50 years)</td>
</tr>
<tr>
<td>High dose of radiation fractions (&gt;2 Gy/day)</td>
</tr>
<tr>
<td>Presence and extent of tumour in or next to the heart</td>
</tr>
<tr>
<td>Lack of shielding</td>
</tr>
<tr>
<td>Concomitant chemotherapy (the anthracyclines considerably increase the risk)</td>
</tr>
<tr>
<td>Cardiovascular risk factors (i.e. diabetes mellitus, smoking, overweight, ≥ moderate hypertension, hypercholesterolaemia)</td>
</tr>
<tr>
<td>Pre-existing cardiovascular disease</td>
</tr>
</tbody>
</table>

High-risk patients definition: anterior or left-side chest irradiation with ≥1 risk factors for RIHD.
Cardiac outcomes in a cohort of adult survivors of childhood and adolescent cancer: retrospective analysis of the Childhood Cancer Survivor Study cohort

Daniel A Mulrooney, assistant professor of paediatrics,1 Mark W Yeazel, assistant professor of family medicine and community health,1 Toana Kawashima, statistical research associate,2 Ann C Mertens, professor of paediatrics,3 Pauline Mitby, senior clinical research coordinator,4 Marilyn Stovall, professor of radiation physics,5 Sarah S Donaldson, professor of radiation oncology,6 Daniel M Green, member ,7 Charles A Sklar, professor of paediatrics,8 Leslie L Robison, member ,9 Wendy M Leisenring, member 9

**Congestive heart failure**

HR=5.9 (95% CI 3.4-9.6)

**Myocardial infarction**

HR=5.0 (95% CI 2.3-10.4)

**Pericardial disease**

HR 6.3 (95% CI 3.3 - 11.9)

**Valvular disease**

HR=4.8 (95% CI 3.0-11.9)
Multiple targets for radiation

(Lancellotti P et al, Expert Consensus on RIHD, EHJ 2013)
ABCDEFG stress echo post-radiotherapy in stress echo 2030
Radiation in cardiology

- Doses to patients
- Risks to patients
- Doses and risks to doctors
- Radiotherapy
- Public health perspective
Small individual risks multiplied by billions of imaging examinations each year become significant population risks.
Eugenio goes to Washington

“I am bothered by the “images are us” culture of the medical community, as discussed by dr. Picano (BMJ, 6 March, 2004). If you listen to news radio here in Washington, every morning you will hear advertisements from heart scans, full body scans, any scans you can think of for asymptomatic patients. Of course, they do not advertise you’re getting remis as you get these scans. They do not advertise radiation at all. There is concern in the U.S. and the FDA about overuse of CT scans with children. And perhaps some actions have been taken, but Dr. Picano sees the need for far more action. I suspect he is right.”


January 18, 2020, JAMA Internal Medicine (Ge and Brown) :
TOP CARDIAC CENTERS OFFER UNPROVEN EXECUTIVE SCREENING (including coronary calcium and coronary CT, at a cost ranging from 1.000 to 25,000 dollars).
From medical radiation dose to cancer risk

“Probably today among top-5 causes of cancer” (Berrington De Gonzalez, 2013)

Source: Doll R and Peto R, 1981

Berrington de Gonzales and Darby, LANCET, 2004

Picano E, Lancet, letter 2004

Berrington de Gonzales, NIH conference May 2013
## Screening for 50 millions Americans:
### Prevention for all?

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Dose CXr</th>
<th>Risk per exam</th>
<th>New cancers/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vascular echo</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Stress echo</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MRI</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CACS-CT</td>
<td>100</td>
<td>1 in 5.000</td>
<td>10,000</td>
</tr>
<tr>
<td>Coronary angiography</td>
<td>250</td>
<td>1 in 2.000</td>
<td>25,000</td>
</tr>
<tr>
<td>Stress SPECT MIBI</td>
<td>500</td>
<td>1 in 1.000</td>
<td>50,000</td>
</tr>
<tr>
<td>MSCT 64 slice</td>
<td>750</td>
<td>1 in 750</td>
<td>65,000</td>
</tr>
</tbody>
</table>

AHA 2009  
BEIR VII, 2006

An information that all (including patients) should know, and all (including physicians) do ignore.
6 MAJOR SOURCES OF ENVIRONMENTAL CONTAMINANTS

1. Industry and Manufacturing
2. Agriculture
3. Modern lifestyles
4. Medical sources: radiation from medical tests such as CT scans
5. Military sources
6. Natural sources

May 10, 2010
Risk vs Benefit: The code of appropriateness

- **I (appropriate indication)**: $B >>> R$
- **IIa (probably appropriate)**: $B >> R$
- **IIb (possibly appropriate)**: $B \geq R$
- **III (inappropriate)**: $R \geq B$

AHA-ACC-ESC Guidelines 2007
What do HCM patients die from?

(Maron B et al A J Cardiol 2016)
A for APPROPRIATENESS (justification principle)

CCT (250 cases)

PCI (250 cases)

CXr (250 cases)

CA (250 cases)

<table>
<thead>
<tr>
<th>Category</th>
<th>Appropriate</th>
<th>Partially Inappropriate</th>
<th>Inappropriate</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CXr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CA</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A for AUDIT (Optimization principle)


The truly given dose in mSv should be spelled-out in the written report (you know what you did)
A for Awareness (justification principle)

- Thallium stress reinjection
- Retrospective gating + aorta
- Prospective triggering
- Sestamibi
- Semiconductor detectors
- PET and N-13 ammonia
- Low voltage setting
- High pitch spiral scanning
- Before training
- After training
- Conventional
- Non-fluoroscopy navigation

MPI | MDCT | Interventional cardiologists yearly exposure | Cardiac radiofrequency ablation

Dr. Marzia Giaccardi, Florence-Santa maria Nova
Dr. Maurizio Del Greco, Trento
Dr. Michela Casella, Milan-Monzino

Increasing concerns about radiation exposure and sustainability of the health care system were the main drivers of the observed reduction in SPECT imaging growth after 2006.
**JUSTIFICATION PRINCIPLE**

**CHEST CT**
- Chest CT 8 mSv
- Sub-M

**RIGHT HEART CATH**
- 5 mSv

**MPI**
- SPECT $^{99m}$Tc – Sestamibi 9.4 mSv
- SPECT $^{201}$Tl stress/rest reinjection 40.7 mSv
- PET $^{13}$N-ammonia stress-rest 2.4 mSv

**CARDIAC FLUOROSCOPIC ABLATION**
- Cardiac arrhythmias

**LUNG ULTRASOUND**
- interstitial lung fibrosis, lung water

**TRANSTHORACIC ECHOCARDIOGRAPHY (TRV or ACT)**
- pulmonary hypertension

**STRESS ECHO**
- myocardial ischemia

**NEAR ZERO FLUOROSCOPY**
- Cardiac arrhythmias
There may be disagreement within the medical community about the accuracy of the risk models. These arguments will not be settled in the near term. However, one fact is undisputable: we must continue our efforts to do a better job of reducing radiation dose to children if and when they need a CT scan.
No more blind date with radiation

• The dose in informed consent forces the doctor to know what he/she should already know *(you know what you are going to do)*

• The truly given dose in mSv should be spelled-out in the written report *(you know what you did)*

• There is no cut-off value between high or low dose: *but the certainly wrong dose is the one we ignore*

• To reduce radiation overexposure and overuse without dose audit is like to treat fever without a thermometer

*Picano E, Vano E, Eurointervention, 2013*
Radio-times, they’re in a changin’

Imaging laboratories: dose mandatory by law (February 7th, 2018, Euratom directive)

Scientific journals: open the chamber of secrets (JACC Instructions for Authors 2017: Dose must be clearly explained)

Scientific societies: ESC position paper 2014; EHRA-HRS 2017, ACC 2018

Closing the evidence gap: Healthy Cath Study (from AIAC and GISE)

Industry: near-zero fluoroscopy, new protective materials, new dosimeters (acoustic, sensitive, real time), new radioprotectors. Low dose technologies are still expensive

Policy makers and Teachers:
“Good training should create a culture of respect for radiation hazard and a commitment to minimize exposure and maximize protection” (Hirschfeld et al, ACC radiation safety position paper, June 18, 2018)
The appropriate and justified use of medical radiation in cardiovascular imaging: a position document of the ESC Associations of Cardiovascular Imaging, Percutaneous Cardiovascular Interventions and Electrophysiology

Eugenio Picano¹, Eliseo Vaño²,³, Madan M. Rehani⁴, Alberto Cuocolo⁵, Lluís Mont⁶, Vicente Bodi⁷, Olivier Bar⁸, Carlo Maccia⁹, Luc Pierard¹⁰, Rosa Sicari¹¹, Sven Plein¹¹, Heiko Mahrholdt¹², Patrizio Lancellotti¹³, Juhani Knuuti¹⁴, Hein Heidbuchel¹⁵, Carlo Di Mario¹⁶, and Luigi P. Badano¹⁷*
X-rays and gamma-rays used in radiology and nuclear medicine are proven (class 1) 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.
Radiation in cardiology: use it wisely!

How to optimize diagnostic and therapeutic procedures for maximum patient safety

Eugenio Picano, MD, PhD

Institute of Clinical Physiology, Pisa, Italy

NO CONFLICTS OF INTERESTS TO DISCLOSE