Assessing Dose to the Lens of the Eye: Current Situation and Challenges

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<table>
<thead>
<tr>
<th>Rank</th>
<th>Tie</th>
<th>Hospital</th>
<th>Points*</th>
<th>High-ranking specialties*</th>
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<tbody>
<tr>
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<td>Massachusetts General Hospital, Boston</td>
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<td>2</td>
<td></td>
<td>Mayo Clinic, Rochester, Minn.</td>
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<td>Johns Hopkins Hospital, Baltimore</td>
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<td>UCLA Medical Center, Los Angeles</td>
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<td>5</td>
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<td>Cleveland Clinic</td>
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<td>Brigham and Women's Hospital, Boston</td>
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<td>New York-Presbyterian University Hospital of Columbia and Cornell, N.Y.</td>
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<td>UCSF Medical Center, San Francisco</td>
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<td>Hospitals of the University of Pennsylvania-Penn Presbyterian, Philadelphia</td>
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<td>Barnes-Jewish Hospital/Washington University, St. Louis</td>
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<td>Northwestern Memorial Hospital, Chicago</td>
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<td>12</td>
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<td>NYU Langone Medical Center, New York</td>
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<td>13</td>
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<td>UPMC-University of Pittsburgh Medical Center</td>
<td>11</td>
<td>8</td>
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<tr>
<td>14</td>
<td></td>
<td>Duke University Hospital, Durham, N.C.</td>
<td>9</td>
<td>6</td>
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<td>15</td>
<td></td>
<td>Stanford Health Care-Stanford Hospital, Stanford, Calif.</td>
<td>8</td>
<td>6</td>
</tr>
</tbody>
</table>
Harvard

• 15 Deans of Schools (HMS* is one)
• 48 Nobel Laureates
• 32 heads of state
• 48 Pulitzer Prize winners

• *Harvard Medical School
Assessing Dose to the Lens of the Eye: Current Situation and Challenges

Main Challenges
WHY do we do what we do?

Medical

• To save lives (by diagnosing and/or treating disease)
• To improve health of individual
• Regulatory compliance
  – Keeping the above objectives
Regulatory compliance

For occupational radiation protection

• We do not want workers to have radiation effects

• What radiation effects?
  – Cancer
  – Skin injuries
  – Cataract
Normally

• \( \approx 99\% \) of workers get <1 mSv against 20 mSv/yr
• 1% includes interventionalists (medical)
• At this level of dose carcinogenic effects are purely hypothetical
• Even if one makes estimation at 5%/Sv, the natural incidence of cancer is 20-40% which is far far more
• Skin injuries area also TOO RARE
Deterministic Risks to Skin

Legs of cardiologist after about 40 years of practice.

Courtesy Stephen Beler, Ph.D. & the cardiologist.
Regulatory compliance

For occupational radiation protection

• We do not want workers to have radiation effects

• What radiation effects
  – Cancer
  – Skin injuries
  – Cataract
You have an opportunity to do a Yeoman Service to occupational radiation protection

Eye dosimetry (& Protection)
Interventional Fluoroscopy

Open surgery

Interventional Procedure
Interventional Procedures
Anaesthetist near the patient and difficult to protect (lead glasses should be used)
Echographist (sometimes difficult to be protected). Measured until 1.2 mSv/procedure over the apron,
Nurse near the patient during a cardiac procedure (difficult to be properly protected). Active electronic dosimeter very useful in these occasions

San Carlos Hospital, Madrid. Courtesy: E Vano
Professionals involved

• Interventional cardiologists
• Interventional radiologists
• Electro physiologists
• Vascular surgeons
• Orthopedic surgeons, urologists, endoscopists using fluoroscopy,
• Other healthcare workers in Interventional suites: nurses, anesthetist, radiographers
Not a Controlled situation versus controlled in nuclear reactor
Eye Lens Opacities $>0.5$

- 38-53% main operators ($\frac{1}{3}$rd to half of main operators) against <20% in controls and relative risk of 2.6 to 5.7.
  - Cumulative eye dose 0.1-43 Gy
  - Age matched controls, statistical significance

- 21-45% in nurses, relative risk of 2.2 to 5.0 and cumulative dose of 1.8-2.1 Gy
The lens of the eye is one of the radiosensitive tissues in the body. Radiation induced cataract has been demonstrated among staff involved with interventional procedures using X rays [ICRP 85; Vano et al., 1998]. A number of studies suggest there may be significant risk of lens opacities in populations exposed to low doses of ionizing radiation. These include those undergoing CT scans [Klein et al., 1993], astronauts [Cucinotta et al., 2001; Rastegar et al., 2002], radiologic technologists [Chodick et al., 2008] radiotherapy [Hall et al., 1999] besides data from atomic bomb survivors [Nakashima et al., 2006; Neriishi et al., 2007] and those exposed in Chernobyl accident [Day et al., 1995].

These observations have clear implications for those working in interventional rooms. Interventionalists and paramedical staff (nurses and to some extent radiographers) remain near the X ray source and within a high scatter radiation field for several hours a day during interventional procedures. During typical working conditions and if radiation protection tools are not routinely used, x-ray exposure to the eyes of interventional physicians and paramedical personnel working in interventional and catheterization laboratories can be high.

The cataract has so far been considered to be a deterministic effect with threshold. The International Commission on Radiological Protection (ICRP) and the U.S. National Council on Radiology Protection
Active collaborators

Eliseo Vano  
Norman Kleiman  
A Minanoto  

Ariel Duran  
KH Sim  
Olivera Ciraj  

Plus a team of local ophthalmologists, interventionalists, medical physicists, RP experts, volunteers


Our Publications


FIRST & Most comprehensive studies
Cataract Risk Points to Need for Better Safety Measures

In light of new research showing increased risk for developing cataracts, interventional personnel are being urged to adopt a number of safety measures. Researchers have found that eye lens opacities can occur even at radiation levels below the currently known threshold values for cataracts.

A study reported during the 2009 meeting of the National Heart Association of Malaysia in Kuala Lumpur showed that interventional personnel have about five times the rate of lens opacities as compared to controls. Published in the June 2010 online version of Catheterization and Cardiovascular Interventions, the study showed a dose-dependent, increased risk of posterior lens opacities for interventional cardiologists and nurses when radiation protection tools were not used. Another study from the...
Questions we often face

1. Can I work full life in cath lab/interventional work?
2. How much work is safe?
3. How to be safe?
Recap of what we have discussed so far

• Why do we do what we do? Purpose beyond regulatory compliance
• Cataract is MAIN radiation risk in ORP among interventionalists
• Almost 1/3rd workers have eye lens opacities
• Potential of carcinogenic risk as monitoring is unsatisfactory
• Hardly training in radiation protection
• Highest users of radiation at close distance without room shielding
• Difficulties in using protective devices
How did we assess eye dose?

• Reconstructions
• Individual interviews based on detailed Form
Eye dosimetry

- Regular eye dosimetry in interventional imaging practically does not exist

Need of Eye dosimetry for
- correlation of observed lens opacities
- compliance with regulatory limits
Assessing Magnitude

Reliable official estimates at global scale are lacking
Magnitude

- 17 million interventional fluoroscopic procedures (USA) (NCRP-2009)
  - 4.6 million cardiac
  - 3.4 million vascular
  - 8.6 million non-vascular
- 8.6% annual increases
Magnitude Assessment

• 3.6 billion x-ray procedures annually (UNSCEAR)
• 1% are interventional & thus 36 M
• A typical interventionalist performs 10 procedures per week, and thus 500 per year.
• Thus number of interventionalists= 36 M divided by 500= 72,000
• For every main operator, there are typically 3-6 persons inside the room (average 4), and thus 288,000 persons globally ≈300,000
Alternative estimation

- 35000 interventional labs
- 35000 mobile surgery labs
- 35000 nuclear medicine labs
- Total 105000 labs
- If one assumes 3 persons in each lab, it amounts to 315,000 persons
Lens opacities (magnitude)

• With 1/3\textsuperscript{rd} likely having lens opacities, this amounts to 100,000 persons having lens opacities

• That shows contribution to improvement in health that can be made
Are these lens opacities avoidable/preventable?

YES
That is what we are doing &

We have success too
Zero gravity
Complete radiation protection

Operator comfort

No lead aprons, no tiredness, no back problems

Free at last

Greater efficiency, more cases
1. Which part of the eye does cataract affect?

There are three predominant forms of cataract depending on their anatomical location (Fig.1) in the eye lens: cortical, nuclear and posterior sub-capsular (PSC). As a person ages, any one type, or a combination of any of these three types, can develop over time. The most common type of age-related cataract, caused primarily by
Radiation and cataract: Patient protection

1. Which X ray procedures and clinical conditions are associated with elevated eye lens doses to the patient?

In procedures such as head CT, paranasal sinus CT, temporal bone and orbital CT and neuro-interventional procedures, the eye is most likely in the field of the primary X ray beam and thus will have the potential to receive a higher dose if appropriate techniques to optimize protection of the eye are not used. Table 2 lists radiation dose to the eye in different examinations and procedures. As is apparent, when the eye is not in the primary beam (for examinations of body areas excluding the head), the scattered radiation dose is very small.

Patients with recurrent and chronic conditions are among those who require frequent examination. As an example, 26% of patients with hydrocephalus receive radiation dose to lenses higher than 150 mSv within 3 years [ST]. In paediatric patients, repeated head CT examinations result in average cumulative dose to lens of the eye of 26 mGy over a few years, but it can be as high as 1.3 Gy [BE].

2. What are typical eye lens doses to patients associated with diagnostic and interventional procedures?

Typical values in terms of absorbed dose to the patient's lens of the eye per procedure are presented in Table 2 below:

Table 1. Typical eye lens doses to patients’ eyes for various X ray procedures in children and adults*

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Dose (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain CT</td>
<td>0.1-1.0</td>
</tr>
<tr>
<td>Paranasal sinus CT</td>
<td>0.1-1.0</td>
</tr>
<tr>
<td>Temporal bone and orbital CT</td>
<td>0.1-1.0</td>
</tr>
<tr>
<td>Neuro-interventional procedures</td>
<td>0.1-1.0</td>
</tr>
</tbody>
</table>

*Typical values based on standard practice.
10 Pearls: Radiation protection of staff in fluoroscopy

Reducing patient dose always results in staff dose reduction

1. Use protective devices!
   - Advisable skirt type lead apron to distribute weight
   - Lead glass eyewear with side protection
   - 0.25 mm lead equivalence but with overlap on front to make it 0.5 mm on the front and 0.25 mm on the back (Provides >90% protection)
   - Thyroid protection

2. Make good use of time-distance-shielding (TDS) principle
   - Minimize time
   - Maximize distance as much as clinically possible

3. Use ceiling suspended screens, lateral shields and table curtains
   - They provide more than 90% protection from scattered radiation in fluoroscopy
   - Mobile floor shielding is advisable when using cine acquisition

4. Keep hands outside the primary beam unless totally unavoidable
   - Hands inside the central area of the primary beam will increase exposure factors (kV, mA) and doses to patient and staff

5. Only 1-5% of radiation falling on the patient’s body exits the other side
   - Stand on the side of the transmitted beam (i.e. by the detector), which contains only 1-5% of the incident radiation and its respective scatter

6. Keep X-ray tube under the patient table and not over it
   - Undercouch systems provide better protection from scattered dose

7. Use personal dosimetry
   - Use at least two dosimeters
     - One inside the apron at chest level
     - One outside the apron at neck or eye level
     - Additional finger ring dosimeter for procedures requiring hands close to primary beam
   - Real time dosimetry systems are useful

8. Update your knowledge about radiation protection

9. Address your concerns about radiation protection to radiation protection specialists (medical physicists)

10. Remember!
   - Quality control testing of fluoroscopy equipment enables safe and stable performance
   - Know your equipment! Using the equipment’s features appropriately will help reduce doses to patients and staff
   - Use injector devices
Measuring scatter dose reduction for different goggles (with correct position of ceiling suspended shielding: Only 4-8 % transmitted)

Courtesy E. Vano, Madrid
Vascular surgery procedure % of the scatter dose measured at the C-arm
San Carlos University Hospital Madrid

Courtesy E. Vano, Madrid
Scatter levels (incorrect position of the ceiling shielding)
In this case: 20-90 % transmitted
(depending of the shielding position)
Measuring scatter dose reduction for different goggles (frontal protection and lateral protection)

Frontal transmission
5 ± 1 %
(max. 7 min. 4)

Lateral transmission
23 ± 16 %
(max. 48 min. 6)
Interventional Radiologists

Haskal & Worgul, RSNA News 2004:14

- Radiologists
- 5/59 posterior subcapsular cataracts
- 22/59 small dot-like opacities (early signs of radiation damage)
- 1/59 had undergone cataract surgery in one eye
Over apron dose (μSv) per procedure (median)

BUT

• We need success in legal dosimetry too
Types of dosimetry

1. Operational dosimetry for protection and education (person behind it)
2. Legal dosimetry (there is service behind monitoring)
Dose metrics

• The eye lens dose, as organ dose is not directly measurable
• According to ICRU the operational quantity $Hp(3)$ is the most appropriate to monitor the eye lens dose, as the lens is covered by about 3 mm of tissue
• Proposals to use $Hp(0.07)$ for eye lens dose monitoring
• Correlations are being attempted with $Hp(10)$
Possible approaches

Practical dosimetry:

1. Passive dosimeters
2. Active dosimeters
3. Retrospective dose assessment using scatter radiation dose levels
4. Correlations between patient dose indices & reference dosimeter and eye doses to the operators
5. Monte Carlo estimations
Problems with Passive dosimetry

• Large number of operators are not wearing personal dosimeters or wear it irregularly

• No passive dosimeter has been accepted for eye dose for regulatory purpose
Possible approaches

Practical dosimetry:

1. **Passive dosimeters**
   (may work for Nuclear reactor but unlikely for Medical)

2. **Active dosimeters**

3. **Retrospective dose assessment using scatter radiation dose levels**

4. **Correlations between patient dose indices & reference dosimeter and eye doses to the operators**

5. **Monte Carlo estimations**
Active dosimeters

• Good for
  – educational purpose and
  – for radiation protection
• You know before your boss knows
• Mostly Not for regulatory compliance
• This is where your role lies
Active dosimetry as Legal

- Settlement of all issues similar to what has been done with passive dosimetry
- How to transfer data to central place (process)
- Who is responsible?
- Financial aspects, lose badge
- How to lock measurements & archive
Technology for Active dosimetry

• Is it matured?
  – Reasonably for practical measurements

• Can be matured for legal part (not a rocket science)

• Industry waiting for your legal requirements to be established
Active dosimetry (as legal)

- Good example: The requirements specify measurement of correct dose
- Not on how to measure (dynamic)
- Allow easier implementation of the new technology
Possible approaches

Practical dosimetry:

1. Passive dosimeters
   (may work for Nuclear reactor but unlikely for Medical)

2. Active dosimeters

3. Retrospective dose assessment using scatter radiation dose levels

4. Correlations between patient dose indices & reference dosimeter and eye doses to the operators

5. Monte Carlo estimations
Possible approaches

Practical dosimetry:

1. Passive dosimeters
   (may work for Nuclear reactor but unlikely for Medical)

2. Active dosimeters

3. Retrospective dose assessment using scatter radiation dose levels

4. Correlations between patient dose indices & reference dosimeter and eye doses to the operators

5. Monte Carlo estimations
Scatter dose at the C-arm vs. KAP

\[
y = 0.011x - 0.036
\]

\[
R^2 = 0.845
\]

mSv vs. KAP (Gy.cm²)
Possible approaches

Practical dosimetry:

1. Passive dosimeters (may work for Nuclear reactor but unlikely for Medical)
2. Active dosimeters
3. Retrospective dose assessment using scatter radiation dose levels
4. Correlations between patient dose indices & reference dosimeter and eye doses to the operators
5. Monte Carlo estimations
EYE DOSIMETRY IN INTERVENTIONAL RADIOLOGY AND CARDIOLOGY: CURRENT CHALLENGES AND PRACTICAL CONSIDERATIONS

O. Ciraj-Bjelac¹,* and M. M. Rehani²
¹Vinca Institute of Nuclear Science, University of Belgrade, M.P. Alasa 12, Vinca, Belgrade, Serbia
²International Atomic Energy Agency (formerly) and European Society of Radiology (ESR), Vienna, Austria

EYE DOSE ASSESSMENT AND MANAGEMENT: OVERVIEW

M. M. Rehani*
Massachusetts General Hospital and Harvard Medical School, Boston, MA, USA
ICRP Draft

- The dosimeter above the apron, at collar level, not only contributes to assessing effective dose but also provides a reasonable estimation of the dose to the eye lens and the head dose.
- Improved methodologies need to be developed to assess eye lens doses when lead glasses are worn. Research programmes should pursue the development of computational technologies (not requiring dosimeters), with personnel position sensing, to assess personnel doses, including eye doses.
Brain tumours among interventional cardiologists: a cause for alarm? Report of four new cases from two cities and a review of the literature.

Roguin A, Goldstein J, Bar O.
Interventional Cardiology, Rambam Medical Center, Bruce Rappaport Faculty of Medicine, the Technion, Israel Institute of Technology, Haifa, Israel. aroguin@technion.ac.il

Abstract

AIMS: Interventional cardiologists who work in cardiac catheterisation laboratories are exposed to low doses of ionising radiation that could pose a health hazard. DNA damage is considered to be the main initiating event by which radiation damage to cells results in development of cancer.

METHODS AND RESULTS: We report on four interventional cardiologists, all with brain malignancies in the left hemisphere. In a literature search, we found five additional cases and thus present data on six interventional cardiologist and three interventional radiologists who were diagnosed with brain tumours. All worked for prolonged periods with exposure to ionising radiation in the catheterisation laboratory.

CONCLUSIONS: In interventional cardiologists and radiologists, the left side of the head is known to be more exposed to radiation than the right. A connection to occupational radiation exposure is biologically plausible, but risk assessment is difficult due to the small population of interventional cardiologists and the low incidence of these tumours. This may be a chance occurrence, but the cause may also be radiation exposure. Scientific study further delineating occupational risks is essential. Since interventional cardiologists have the highest radiation exposure among health professionals, major awareness of radiation safety and training in radiological protection are essential and imperative, and should be used in every procedure.
Brain cancer in interventional cardiologists and physicians - is occupational radiation exposure the cause?

Jackson G.

Comment on
Brain tumours among interventional cardiologists: a cause for alarm?

Report of four new cases from two cities and a review of the literature

<table>
<thead>
<tr>
<th>Country</th>
<th>[Ref] and publication year</th>
<th>Year diagnosed</th>
<th>Age</th>
<th>Years of radiation exposure [Latency period]</th>
<th>Type</th>
<th>Side</th>
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</thead>
<tbody>
<tr>
<td>Haifa, Israel</td>
<td></td>
<td>1998</td>
<td>48</td>
<td>14</td>
<td>Meningioma</td>
<td>Left side</td>
</tr>
<tr>
<td>Paris, France</td>
<td></td>
<td>2001</td>
<td>56</td>
<td>25</td>
<td>Glioblastoma</td>
<td>Left side</td>
</tr>
<tr>
<td>Paris, France</td>
<td></td>
<td>2005</td>
<td>49</td>
<td>22</td>
<td>Glioblastoma</td>
<td>Left side</td>
</tr>
<tr>
<td>Haifa, Israel</td>
<td></td>
<td>2009</td>
<td>62</td>
<td>32</td>
<td>Glioblastoma</td>
<td>Left side</td>
</tr>
</tbody>
</table>

Mice: medulloblastoma
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<tr>
<th>STUDY, YEAR</th>
<th>METHODS</th>
<th>FINDINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matanoski et al., 1975 [32]</td>
<td>Cohort study of mortality in 6,500 US male radiologists (years first worked 1920–1969) over a 50-year period</td>
<td>Excess cancer risk among radiologists compared with other physicians</td>
</tr>
<tr>
<td>Wang JX et al., 1990 [33]</td>
<td>Cohort study of Chinese diagnostic x-ray workers (1950 to 1985)</td>
<td>Trend of excess cancer risk (standardized incidence ratio 1.2 for employment duration 10–14 years; 2.3 for 15–19 years) compared to non-radiation medical workers, not available for brain cancer</td>
</tr>
<tr>
<td>Andersson M et al., 1991 [34]</td>
<td>Cohort study of Danish radiation therapy workers</td>
<td>Trend of excess cancer risk (standardized incidence ratio 1.09 with measured radiation dose &lt; 5 mSv, and 2.23 with dose 5–50 mSv), not available for brain cancer</td>
</tr>
<tr>
<td>Carozza et al., 2000 [35]</td>
<td>Case–control study of occupation and glioma</td>
<td>Physicians at increased, albeit imprecise, risk of glioma (OR 3.5, CI 0.7- 17)</td>
</tr>
<tr>
<td>Andersen M et al., 1999 [36]</td>
<td>Population-based study of occupation and cancer incidence (from the 1990s to 1980s)</td>
<td>Brain cancer increased among physicians in general; no breakdown by specialty</td>
</tr>
<tr>
<td>Hardell et al., 2001 [37]</td>
<td>Case control study of 233 gliomas</td>
<td>Excess cancer risk of 6.0 in fluoroscopists</td>
</tr>
<tr>
<td>Blettner et al., 2007 [38]</td>
<td>Case control study of German patients (age 30–59 years at diagnosis) with brain cancer in 2001–2003</td>
<td>Occupational exposure (physicians, nurses, radiographers) with OR 2.49 (0.74–8.38) for neurinoma, OR close to 1 for glioma and meningioma</td>
</tr>
<tr>
<td>Roguin et al., 2012 [40]</td>
<td>Report of a case cluster (2000s)</td>
<td>3 brain gliomas and 1 meningioma, left-sided, in 4 interventional cardiologists</td>
</tr>
</tbody>
</table>
Mortality in U.S. Physicians Likely to Perform Fluoroscopy-guided Interventional Procedures Compared with Psychiatrists, 1979 to 2008

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To compare total and cause-specific mortality rates between physicians likely to have performed fluoroscopy-guided interventional (FGI) procedures (referred to as FGI MDs) and psychiatrists to determine if any differences are consistent with known radiation risks.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials and Methods:</td>
<td>Mortality risks were compared in nationwide cohorts of 45834 FGI MDs and 64401 psychiatrists. Cause of death was ascertained from the National Death Index. Poisson regression was used to estimate relative risks (RRs) and 95% confidence intervals (CIs) for FGI MDs versus psychiatrists, with adjustment (via stratification) for year of birth and attained age.</td>
</tr>
<tr>
<td>Results:</td>
<td>During follow-up (1979-2008), 3506 FGI MDs (86 women) and 7614 psychiatrists (5677 women) died. Compared with psychiatrists, FGI MDs had lower total (men: RR, 0.80 [95% CI: 0.77, 0.83]; women: RR, 0.80 [95% CI: 0.63, 1.00]) and cancer (men: RR, 0.92 [95% CI: 0.85, 0.99]; women: RR, 0.83 [95% CI: 0.58, 1.18]) mortality. Mortality because of specific types of cancer, total and specific types of circulatory diseases, and other causes were not elevated in FGI MDs compared with psychiatrists. On the basis of small numbers, leukemia mortality was elevated among male FGI MDs who graduated from medical school before 1940 (RR, 3.86; 95% CI: 1.21, 12.3).</td>
</tr>
<tr>
<td>Conclusion:</td>
<td>Overall, total deaths and deaths from specific causes were not elevated in FGI MDs compared with psychiatrists. These findings require confirmation in large cohort studies with individual doses, detailed work histories, and extended follow-up of the subjects to substantially older median age at exit.</td>
</tr>
</tbody>
</table>

*RSNA, 2017

Online supplemental material is available for this article.
Conclusions from recent paper

• Overall, total deaths and deaths from specific causes were not elevated in MDs performing Fluoroscopic guided interventions as compared with psychiatrists.

• These findings require confirmation in large cohort studies with individual doses, detailed work histories, and extended follow-up of the subjects to substantially older median age at exit.
Key Messages

• Eye protection and dosimetry is the key in occupational protection
• Good progress on protection of eye
• Active dosimetry is the future
• Need for action on transitioning to modern dosimetry for legal dosimetry
• Call for Action to Industry
Thank You

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mrehani@mgh.harvard.edu