Interventional cardiology and X-ray exposure of the head: overview of clinical evidence and practical implications

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Interventional cardiology and X ray exposure of the head: overview of clinical evidence and practical implications.

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Abstract

Interventional cardiologists are significantly exposed to x-rays and no dose of radiation may be considered safe or harmless. Leaded aprons protect the trunk and the thyroid gland, leaded glasses protect the eyes. The operator's legs, arms, neck and head are, instead, not fully protected.

In fact, the operator's brain remains the closest part to primary X-ray beam and scatter in most interventional procedures and specifically the physician's front head is the most exposed region during device implantation performed at the patient's side. Since the initial description of cases of brain and neck tumors, additional reports on head and neck malignancies have been published. Although a direct link between operator radiation exposure and brain cancer has not been established, these reports have heightened awareness of a potential association. The use of lead-based cranial dedicated shields may help reduce operator exposure but upward scattered radiation, weight and poor tolerability have raised concerns and hindered widespread acceptance.

The purpose of this review is to describe current knowledge on occupational x-ray exposure of interventional cardiologists, with a special focus on the potential risks for the head and neck and efficacy of available protection devices.

Introduction

Radiation exposure is a proven hazard during invasive medical procedures guided by fluoroscopy and despite recent developments it is still associated with radiation exposure for patients, staff and physicians[1]. Since the number of invasive electrophysiology (EP) procedures in the last years is growing worldwide, interventional cardiologists performing these procedures (e.g. electrophysiologists) are exposed to significant radiation dose (with higher doses in more complex procedures, such as in atrial fibrillation ablation and cardiac resynchronization device implantation). No dose of radiation may be considered safe or harmless. All medical x-ray exposure should be kept "as low as reasonably achievable". A lack of accurate knowledge and misinformation regarding the hazard of occupational radiation exposure may lead to overuse of x-rays and underuse of personal protection equipment[2,3,4]. In fact, radiation dose is not only influenced by the imaging time. Depending on the nature of the procedure, the exposure of the patient and the staff may be influenced by the image quality needed to perform the procedure safely and efficiently (tube angulations, collimation, patient BMI), hardware (detector size, image settings) and laboratory setup (use of protective equipment, position of operator)[5].

Recently, the EHRA and the International Commission on Radiological Protection (ICRP) have issued several guidelines to reduce radiation exposure for patients and operators during electrophysiological procedures[6]. Although the deterministic and stochastic effects of ionizing radiation direct exposure to high-dose are well described, the effects of long-term radiation exposure are less known[4].

The annual head dose sustained by interventional cardiologists, for example, may reach 60 mSv. Since an initial report on few cases of brain and neck tumors, additional reports detailing several head and neck malignancies, with the left side of the brain disproportionately involved have been published[7,8,9]. Although a direct link between operator radiation exposure and brain cancer has not been established, these reports have heightened awareness of a potential association. Further, brain irradiation can have direct radiation effects on the thyroid and pituitary glands. The use of lead-based cranial dedicated shields may help reduce operator exposure but upward scattered radiation coming from the patient may challenge protection[10].

The purpose of this review is to describe the current knowledge on occupational x-ray exposure in the electrophysiology laboratory, with a special focus on the potential risks for the head and neck and efficacy of available protection devices.

Prevalence of the problem

A total of 1,087,259,488 people live in the European Society of Cardiology (ESC) member countries[11]. Every year patients and interventional cardiologists are exposed to x-ray for diagnostic or therapeutic exams in a hemodynamic or EP lab (in Italy 331 hospitals have an EP lab). In 2016, for example, EHRA association calculated an amount of 296.798 ablations (26.982 registered in Italy), 547.586 PM implantations (65.100 in Italy) and 105.730 ICD implantations (14.500 in Italy): to each procedure corresponds an x-ray exposure of the head for both patient and operator, with the latter, however, being chronically exposed.

The epidemiology of brain tumors is unclear and few world-data are available (Table 1). Epidemiological studies of subjects who received head irradiation during childhood report increased risk of malignant and benign intra-cranial tumors: this excess risk seems to decrease with increasing age at exposure. In the general population the incidence rate for primary brain tumors ranges between 4,3 to 18,6 per 100,000 per years[12]. A study of Davies and colleagues[13] reported a prevalence of all primary brain tumors of 221 per 100.000, with gliomas being 6 per 100.000 and meningiomas 6 per 100.000. The National Cancer Institute estimates an annual incidence of brain and other nervous system cancers of 0.2% in the general population, while the true incidence in healthcare workers exposed to radiation is currently unknown[14].

A cohort mortality study among workers exposed to ionizing radiation in U.S. was published in 2001[15], with 3.8 person-years of observation among 140,000 white male workers: the increased risk of brain tumor was highly consistent, by a magnitude of 15–30%. All brain malignancies seemed equally distributed between both sides but in 2013 Roguin et al. reported 25 brain and neck tumor cases in interventional cardiologists in which 85% of malignancies were on the left side[9].

Blettner et al.[16] indicated, on the other hand, no increased risk after occupational exposure to ionizing radiation for glioma and meningiomas, but an increased risk was observed for acoustic neuroma (OR = 2.49).

X-ray ocular effects

The lens of the eye is one of the most radiosensitive tissues in the body, and exposure of the lens to ionizing radiation can cause cataract (Table 2). The single dose threshold that may cause vision-impairing cataracts in humans is not well characterized but is believed to be about 500 mGy, with a minimum latency of approximately 1 year[17]. The correlation between radiation exposure in interventional cardiology and the development of cataracts has been demonstrated since over a decade.

In 2013 Vano et al. studied 58 physicians and 69 nurses and technicians employed in a catheterization laboratory: they found posterior subcapsular lens abnormalities in 50% of the interventional cardiologists and 41% of the nurses and technicians, compared to <10% in a control group[18]. A more recent meta-analysis of eight studies involving 2559 interventional cardiologists and catheterization lab staff reported a more than 3-fold increase in risk of posterior lens opacity in this group compared to controls (RR 3.21)[19].

Eventually, a cross-sectional multicenter study compared a radiation exposed group of 106 interventional cardiologists from different French centers with an unexposed control group of 99 subjects. The prevalence of either nuclear or cortical lens opacities was similar, but the posterior subcapsular segment lens opacities were significantly more frequent among radiation workers (17% vs. 5%, p=0.006)[20].

For these reasons, undoubtfully lead glasses are an important component of the protection of the eyes against scattered radiation and they are strongly recommended by the international consensus documents[5].

Dementia

Dementia global prevalence is dramatically increasing up to 80 million patients by 2040. The prevalence at ages below 64 is low: in 2014 the prevalence rate for the age group 45 - 64 was less than 0.02%[21]. For the age group 64 – 69, however, it increased to 1.3% and for ages 70 – 74, to 2.9%, with a further increase by about double for every five years thereafter. Dementia is even more prevalent within subjects exposed to radiation (radiotherapy, bomb survivors, survivors of nuclear accidents, nuclear workers, radiologists and interventional cardiologists; Table 3). Up to 50% of subjects who experienced brain irradiation therapy, for example, are known to develop progressive dementia[22]. As confirmed in animal models, radiation leads to progressive impairment of cognitive function and/or walking coordination. Ungvari et al. nicely demonstrated in a mice model the microvascular injury visible 3 months after irradiation[23]. In a Japanese population exposed to radiation (atomic bomb survivors) dementia prevalence was, in fact, estimated 7,2% (vascular dementia 2% in men and 1,8% in women)[24].

The finding by Andreassi and colleagues on an increased subclinical carotid intima-media thickness (on the left side) and telomere length shortening due to long term ionizing radiation exposure in the cardiac catheterization lab workers clearly suggests accelerated vascular aging and early atherosclerosis in these subjects[25].

Head protection

Interventionists are chronically exposed to ionizing radiation. Several reports have documented that interventional cardiologists are the most exposed among any medical staff using X-rays. Previous reports underscore that the cardiologists' annual radiation exposure ranges from 20 to 30 mSv/year[26], with left side of the head experiencing twice the exposure levels of the right side[9]. Dose to the head is lower in operators taller than 180 cm in height, with a decrease in dose to the head of 1% per cm of operator height[27].

The use of shielding equipment should therefore be mandatory to mitigate the risk of radiation exposure. Leaded aprons protect the trunk and the thyroid gland, leaded glasses protect the eyes. The operator's legs, arms, neck and head are, instead, not fully protected despite the use of additional indirect table-side and drop-down shields. In fact, the operator's brain remains the closest part to primary X-ray beam and scatter in most interventional procedures and specifically the physician's front head is the most exposed region during device implantation performed at the patient's side. For this reason, specific cranial protective caps are being marketed as devices that significantly decrease brain exposure during fluoroscopically guided interventions and potentially avoid irreversible damages to brain tissues[28]. However, although cranial caps potentially reduce exposure, weight and poor tolerability have raised concerns and hindered widespread acceptance.

Available devices and efficiency

Technological advancements in fluoroscopic equipment and the use of lead-based shields have helped to reduce operator exposure to radiation scatter; however dedicated cranial protection has been, up to date, limited, due to low risk awareness[29] and poorly tolerated devices. Lead caps have shown to be effective in lowering the exposure to the head by up to 30 times more than ceiling-mounted lead shields. Observational studies reported a significant reduction in radiation exposure with these leads[30]; however, the average weight of the caps make them uncomfortable to wear and potentially presenting occupational health hazards themselves. In addition, although they are generally reusable, the lifespan of a cap is unknown and will depend on its care. In any case, while they do provide substantial dose reduction, whether they prevent radiation-induced illness is unknown.

Different options of lead caps are, to date, available:

- *Lead cap 1.14 Kg in weight and 0.5 mm lead equivalent protection* (Burkhart Roentgen International, St Petersburg, Florida, USA). This cap wraps the head and neck leaving an opening for the eyes, nose, and mouth. It is quite heavy and may be uncomfortable to wear.

- *Lead equivalent cap containing a barium sulphate-bismuth oxide composite*. Average weight 125g. *No Brainer, Radpad* (Worldwide Technologies and Innovations, Kansas City, KS). Available in four levels of protection, based on the thickness of the shielding heavy metals, ranging from 0.06 mm to 0.375 mm lead equivalent at 90 kVP. It contains bismuth and barium to block radiation and is lead free. It provides radiation protection for the head over an entire day of invasive procedures. It is disposable but could be used repeatedly by the same operator over multiple procedures. The cap is to be worn as far down forehead as possible to maximize protection.

XFP attenuating cap (BLOXR Solutions, West Valley, Utah). The cap is composed of a flexible strip of a bilayer of barium sulfate and bismuth oxide constructed into a semi disposable surgical cap with lightweight cloth. The material has been shown to significantly attenuate radiation equivalent to a 0.5 mm thick lead barrier. The cap is available in multiple sizes that all weigh 144 g.

In 2015 the BRAIN (Brain Radiation Exposure and Attenuation During Invasive Cardiology Procedures) study tested the XFP cap for protection during invasive cardiology procedures. The six dosimeters placed inside the cap recorded a significantly lower (16-fold) radiation exposure compared to those placed outside the cap. In addition, the cap was judged as minimally noticeable on a semiquantitative scale[4].

A recent study, instead, tested the radioprotection efficacy of the lightweight lead equivalent caps containing barium sulphate-bismuth oxide composite. These caps provided up to 90% dose reduction to the head, and the average weight of 125 g made the cap comfortable to wear[31].

Newer, even lighter caps, based on the same materials (Radpad), have been tested with dosimeters inside and outside the cap on protecting the left temporal region and resulted able to reduce the radiation dose to the head by 76% during coronary angiography interventions. The mean left temporal external-internal radiation dose difference was 4.79 [95% CI, 3.30-6.68] Sv. The mean left chest radiation dose, as a function of the air Kinetic Energy Released in Matter (kerma, measure of the energy of an x-ray beam per unit mass in a small irradiated air volume), was reduced by 72%. In more detail, a significant reduction of head dose with the cap occurred in both the lead drape (2.73 with 95% CI, 1.76-4.00; P<0.001) and nonlead drape groups (7.69 with 95% CI, 5.64-10.19; P<0.001).

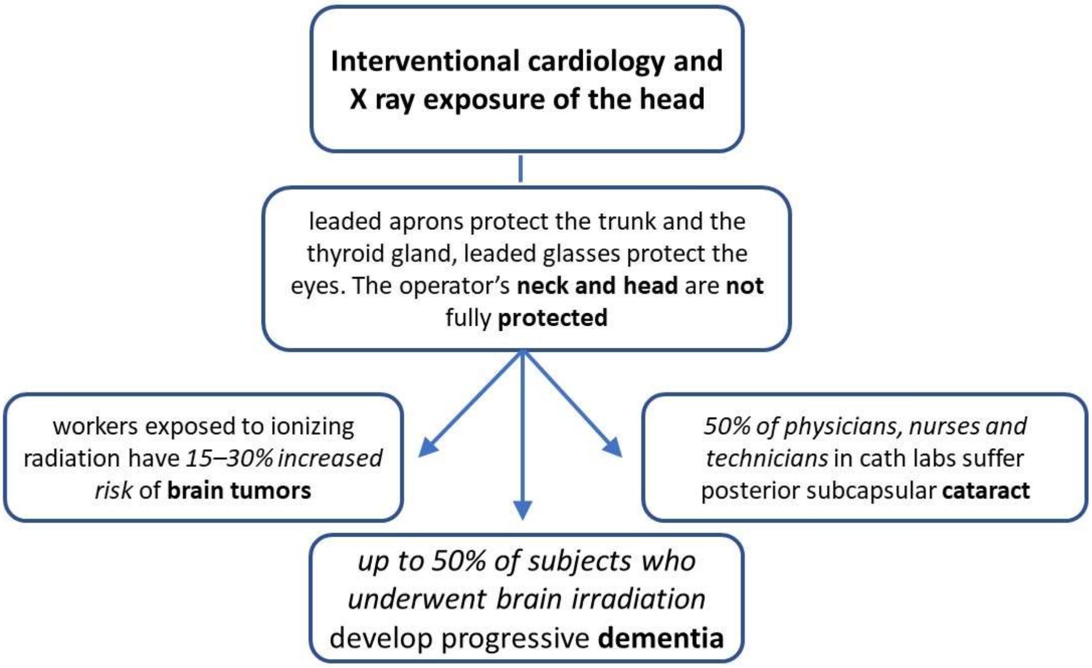
Operators reported comfort level with the cap during the procedure was 9 on a 1- to 10- point scale[32]. Interestingly, however, when tested in left subpectoral device implant procedures, with the right half of the operator's front head as the most exposed region, the Radpad cap attenuated the skin front-head exposure but not provided protection to the brain[10]. The exposure of the anterior part of the brain is decreased by the skull by a 4.5-fold compared to the front-head skin value, however, this study confirms previous evidence that most of the radiation to an interventionalist's brain originates from scatter radiation from angles not shadowed by a protection cap[26]. In fact, when the Radpad cap is worn as a protruding horizontal plane it was able to decrease brain exposure by a 1.7 fold[10].

Conclusion

Interventional cardiologists are significantly exposed to x-rays and no dose of radiation may be considered safe or harmless. Leaded aprons protect the trunk and the thyroid gland, leaded glasses protect the eyes. The operator's neck and head are not fully protected.

Although a direct link between operator's head radiation exposure and malignancies has not been established, the present review heightens awareness of a potential association. The use of dedicated cranial protection devices may help reduce operator exposure but upward scattered radiation, weight and poor tolerability have raised concerns and hindered widespread acceptance.

Figure 1. Current knowledge on occupational x-ray exposure of interventional cardiologists and the risks for the head.



Tables

Table 1. Main studies reporting head and neck malignancies following x-ray exposure.

AUTHOR, JOURNAL, YEAR	TITLE	METHODS	FINDINGS
Roguin, Eurointervention 2012	Brain tumors among interventional cardiologists: a cause for alarm? Report of four new cases from two cities and a review of the literature	Case clusters (2000s)	3 brain gliomas and 1 meningioma, left-sided, in 4 interventional cardiologists
Roguin, Am J Cardiol 2013	Brain and neck tumors among physicians performing interventional procedures	Case clusters (2000s)	31 brain and neck tumors. 17 gliobastomas multiforme, 2 astrocytomas, 5 meningiomas. The maligancy was left sided in 22 cases (85%)
Picano, BMC Cancer 2012	Cancer and non-cancer brain and eye effects of chronic low-dose ionizing radiation exposure	Review of the effects on the brain (cancer and non-cancer) of chronic low dose radiation exposure	Epidemiological evidence for radiation induced brain cancer is suggestive but by no mean conclusive
Pearce, Lancet 2012	Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumors: a retrospective cohort study	Retrospective cohort study including patients without previous cancer who were first examined with CT	Positive association between radiation dose from CT scans and brain tumors (0·023, 0·010-0·049; p<0·0001). Glioma (p=0.0033), Meningioma, and Schwannoma (p=0.0195)
Venneri, Am Heart J 2009	Cancer risk from professional exposure in staff working in cardiac catheterization laboratory: insights from the Nation- al Research Council's Biological Effects of Ionizing Radiation VII Report	Data from 26 (7 women, 19 men; age 46 +/- 9 years) workers of the cardiovascular catheterization laboratory with effective dose >2 mSv	Risk of fatal cancer was 1 in 384. The median risk of fatal and nonfatal cancer was 1 in 192 (interquartile range = 1 in 137-1 in 370)
Andreassi, Circ Cardiovasc Interv 2016	Occupational health risks in cardiac catheterization laboratory workers	Self-administered questionnaire on 746 subjects, 466 exposed (281 males; 44±9 years) and 280 unexposed	Highly exposed physicians had an adjusted odds ratio of 4.5 for cancer (95% confidence interval: 0.9-25; P=0.06). No brain tumors

Table 2. Main studies reporting on the correlation between cataract and x-ray exposure.

AUTHOR, JOURNAL, YEAR	TITLE	METHODS	FINDINGS
Vano, Journal of Vascular and Interventional Radiology 2013	Radiation-associated lens opacities in catheterization personnel: results of a survey and direct assessment	58 physicians and 69 nurses and technicians compared to unexposed age-matched controls	Posterior subcapsular lens changes in 50% of the interventional cardiologists and 41% of nurses and technicians compared to <10% within controls
Boveda, International Journal of Cardiology 2013	Interventional cardiologist and risk of radiation-induced cataract: result of a French multicenter interventional study	Cross-sectional multicenter study. 106 interventional cardiologists compared to 99 controls	17% vs. 5%, p=0.006 posterior subcapsular cataract (OR 3.9)
Karatasakis, Catheter Cardiovasc Interv 2018	Radiation-associated lens changes in the cardiac catheterization laboratory: Results from the IC-CATARACT (CATaracts Attributed to RAdiation in the CaTh lab) study.	Cross-sectional study on 117 interventional cardiologist (ICs) vs controls	Compared with unexposed controls, ICs and cath-lab staff had higher prevalence of lens changes (47 vs 17% p=0.015).
Elmaraezy, Catheter Cardiovasc Interv 2017	Risk of cataract among interventional cardiologists (ICs) and catheterization lab staff: A systematic review and meta-analysis	Meta-analysis of eight studies involving 2559 subjects	Posterior lens opacity was significantly higher in ICs relative to the control group (RR= 3.21, 95% CI [2.14, 4.83], P < 0.00001)

Table 3. Main studies reporting on the correlation between dementia and x-ray exposure.

AUTHOR, JOURNAL, YEAR	TITLE	METHODS	FINDINGS
Andreassi, JACC Cardiovascular Intervention 2015	Subclinical carotid atherosclerosis and early vascular aging from long-term ionizing radiation exposure: a genetic, telomere, and vascular ultrasound study in cardiac catheterization laboratory	Left and right carotid intima-media thickness (CIMT) in 223 cath lab personnel and 222 unexposed subjects	Left, right, and averaged CIMTs significantly increased in high-exposure workers (all p values<0.04). On the left side, significant correlation between CIMT and ORRS (p=0.001)
Douw, Lancet Neurol 2009	Cognitive and radiological effects of radiotherapy in patients with low grade glioma: long term follow-up	Radiological and cognitive abnormalities in survivors of low-grade glioma at a mean of 12 years after diagnosis	Patients receiving radiotherapy had more deficits that affected attentional functioning at follow-up, regardless of fraction dose (p=0.003)
Marazziti, J Int Neuro-psychol Soc 2015	Neuropsychological Testing in Interventional Cardiology Staff after Long-Term Exposure to Ionizing Radiation	Comparison of neuropsychological scores in 83 cardiologists and nurses (exposed group, EG) working in the cardiac catheterization laboratory, with 83 controls (non exposed group, nEG)	EG participants significantly lower scores on the delayed recall, visual short-term memory, and semantic lexical access ability than nEG
Borghini, Circulation 2017	Low-dose exposure to ionizing radiation deregulates the brain-specific microRNA-134 in interventional cardiologists	Microarray analysis (Agilent Human miRNA Microarray) performed on plasma from 10 interventional cardiologists and 10 age- and sex-matched unexposed controls	Circulating brain miR-134 and miR-2392 expression profiles were significantly downregulated in interventional cardiologists

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