ORIGINAL RESEARCH

Cranial radiation exposure during cerebral catheter angiography

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ABSTRACT

Background Radiation exposure to patients and personnel remains a major concern in the practice of interventional radiology, with minimal literature available on exposure to the forehead and cranium.
Objective In this study, we measured cranial radiation exposure to the patient, operating interventional neuroradiologist, and circulating nurse during neuroangiographic procedures. We also report the effectiveness of wearing a 0.5 mm lead equivalent cap as protection against radiation scatter.
Design 24 consecutive adult interventional neuroradiology procedures (six interventional, 18 diagnostic) were prospectively studied for cranial radiation exposures in the patient and personnel. Data were collected using electronic detectors and thermoluminescent dosimeters.
Results Mean fluoroscopy time for diagnostic and interventional procedures was 8.48 (SD 2.79) min and 26.80 (SD 6.57) min, respectively. Mean radiation exposure to the operator's head was 0.08 mSv, as measured on the outside of the 0.5 mm lead equivalent protective headgear. This amounts to around 150 mSv/year, far exceeding the current deterministic threshold for the lens of the eye (ie, 20 mSv/year) in high volume centers performing up to five procedures a day. When compared with doses measured on the inside of the protective skullcap, there was a statistically significant reduction in the amount of radiation received by the operator's skull.
Conclusions Our study suggests that a modern neurointerventional suite is safe when equipped with proper protective shields and personal gear. However, cranial exposure is not completely eliminated with existing protective devices and the addition of a protective skullcap eliminates this exposure to both the operator and support staff.

INTRODUCTION

Radiation exposure to patients and personnel remains a major concern in the practice of interventional radiology.[1–7] Medical personnel using radiation now account for more than half of all radiation workers exposed to manmade sources of radiation.[4] While scatter radiation exposure to the lens of the eye and regions below the neck have been quantified and minimized using a variety of protective equipment,[8–13] not much literature is available on exposure to the forehead and skull.[14 15] Radiation exposure to the human eye is known to cause cataracts,[16–18] while cranial exposure remains the only established environmental risk factor for gliomas and meningiomas.[14 19–24] Many radiologists and cardiologists now use leaded glasses and ceiling suspended shields for eye and body protection. Studies from interventional cardiology literature warn of head exposures in excess of the occupational limit of 150 mSv/year that was established as the upper limit for lens exposure.[25] Current guidelines from the International Commission on Radiological Protection have now limited this exposure to 20 mSv/year.[26] However, not much has been written about cranial exposure in the modern neurointerventional suite.[15]

Of the brain tumors associated with ionizing radiation exposure, the best studied is meningioma, where the risk is known to increase from 6 to 10-fold.[20 22 27] The best known epidemiological evidence comes from studying the effect of ionizing radiation on Israeli children, between 1948 and 1960, whose scalps were irradiated for tinea capitis and later showed a 10-fold increase in the incidence of meningiomas.[28] Other reports have come from full mouth x-ray studies for dental diagnosis,[29–31] diagnostic x-ray exposure of the skull,[19] and cranial irradiation for tumor treatment.[27 29] Hence cranial exposure has been a major concern for the diagnostic and interventional radiologist. A recent study reported nine cases of left hemispheric malignancies in interventional radiologists and cardiologists, raising awareness to this important occupational risk.[14 21 32] A recent study on phantom head exposure from the interventional cardiology literature reported benefit of a 0.5 mm lead equivalent cap to reduce cranial exposure.[15]

Here we report the cranial radiation exposure to the patient, operating interventional neuroradiologist, and the circulating nurse during neuroangiographic procedures in 24 prospective patients in a modern neurointerventional suite. We also report the effectiveness of wearing a 0.5 mm lead equivalent cap as protection against radiation scatter.

MATERIALS AND METHODS

Study design

We prospectively studied cranial radiation exposures of the patient, interventional radiologist, and circulating nurse in 24 consecutive adult interventional neuroradiology procedures performed at the University of New Mexico Hospital, Albuquerque, New Mexico, from July 2011 to December 2011. No informed consent was required as the study was classified as a 'quality assurance study'. All procedures were done on Allura Xper FD20/20 Biplane neuro x-ray system (Philips, Andover,

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Massachusetts, USA). The procedures included standard diagnostic cerebral angiograms and cranial vascular interventional procedures (table 1). Radiation exposure data were collected on each case using NAVLAP accredited (National Voluntary Laboratory Accreditation Program) electronic detectors (Instadose, Mirion Technologies, California, USA) placed on the temporal scalp facing the radiation source for the operator and nurse (ie, left temporal scalp of the operator and right temporal scalp of the nurse), while patient exposure was collected using two thermoluminescent dosimeters (TLD-100, Quantaflux, Ohio, USA) placed on the table top directly under the patient's head. To control for body habitus and procedure variabilities, the entire study was done by one operator (a neurosurgery resident) wearing a 0.5 mm lead equivalent skullcap (Radpad Protection, Worldwide Innovations and Technologies, Inc, Kansas, USA) with the supervising physician standing to his right side. Two electronic dosimeters, one on the inner side and one on the outer side of the protective skullcap, were placed on the left side of the operator. A third electronic dosimeter was placed on the side of the ceiling mounted leaded acrylic shield facing the radiologist, while the fourth electronic detector was placed on the right temporal scalp of the circulating nurse who spent most of the time on the anesthesiologist side across the table.

To measure actual radiation exposure to the patient's scalp, two thermoluminescent dosimeters (TLD-100) were placed directly under the patient's occiput on the procedure table. These were then read separately from the electronic dosimeters. A separate experiment was performed to standardize measurements obtained from the two dosimeters so they could be reported in comparable units. For this purpose, four TLD-100 dosimeters were exposed to a fluoroscopic beam next to a head phantom (two on each side) with two NAVLAP accredited electronic dosimeters (Instadose) placed next to the TLD-100 dosimeters. The measurements thus obtained were used for comparison determination across the two dosimeters.

All staff adhered to the standard radiation safety protocols by wearing personal protective equipment that included leaded aprons and thyroid shields for everyone in the room, 0.75 mm lead equivalent glasses, and a 0.5 mm lead equivalent skullcap for the participating resident and attending. A ceiling mounted 0.5 mm leaded acrylic shield and a 0.5 mm lead equivalent waist down shield protected the radiologist from shoulder height down.

In addition to the radiation exposure detected by individual dosimeters, standard measurements given by the machine, including reported cumulative exposure (RCE), total fluoroscopy time, and dose area product (DAP), were also noted.

Statistical analysis

Descriptive statistics, including means, SDs, medians, and quartiles, were calculated to summarize fluoroscopy time, RCE, DAP, and radiation exposure to each of participants (ie, patient, operator, and nurse), both overall and by group. None of the variables was normally distributed requiring us to perform non-parametric tests to determine whether any differences in radiation exposure existed between the diagnostic and interventional groups. As such, all p values reported in this study are from the Wilcoxon rank sum test. We report means and medians in table 1, although it can be noted that the median exposure for several variables was zero, and to assist in interpretation, means and SDs are discussed in the text. All analysis was performed in SAS V.9.3 (SAS Institute, Cary, North Carolina, USA, 2010).

RESULTS

A total of 24 neurointerventional studies were prospectively included. Of these, 18 were diagnostic cerebral angiograms and six included interventions for vascular malformations, such as aneurysms and arteriovenous malformations (table 1). Mean fluoroscopy time for diagnostic and interventional procedures was 8.48 (SD 2.79) and 26.80 (SD 6.57) min, respectively.

Patient cranial radiation exposures

The overall mean RCE to the patient was 658.54 mGy (SD 321.43) while the mean DAP measurement was 131 981.42 mGy/cm^2 (SD 53 204.25). These values differed with the type of procedures performed—that is, for diagnostic and interventional procedures, mean RCE values were 547.54 mGy (SD 217.54) and 991.54 mGy (SD 370.07), respectively whereas mean DAP values were 119 322.94 mGy/cm^2 (SD 41 865.65) for diagnostic and 169 956.83 mGy/cm^2 (SD 68 952.75) for interventional procedures. The cranial radiation entrance dose received by the patient (ie, mean dose reported by the two TLD-100 dosimeters placed directly under the patient's head) was 220.27 mSv (SD 221.17). Patient cranial radiation exposure also differed between the types of procedures performed—198.60 mSv for diagnostic and 991.54 mSv for interventional procedures.

Staff cranial radiation exposures

The ceiling mounted leaded acrylic protective shield significantly blocked scatter radiation from traveling to the operator side. The overall mean radiation dose, as measured by the electronic dosimeter on the operator side of the ceiling mounted shield, was 0.0017±0.0082 mSv. Mean radiation exposure to the operator's head was 0.08 mSv (SD 0.19), as measured on the outside of the 0.5 mm lead equivalent protective headgear.

Table 1 Summary of cranial radiation exposure to patients and staff

	Total procedures (n=24)	Diagnostic procedures (n=18)	Interventional procedures (n=6)	p Value
Fluoroscopy time (min)	13.06±8.99	8.4±2.79	26.8±6.56	<0.01
Operator head (outside cap) (mSv)	0.08±0.19	0.087±0.22	0.05±0.07	
Operator head (inside cap) (mSv)	0.005±0.016	0.005±0.016	0.006±0.016	
Nurse head (mSv)	0.03±0.06	0.012±0.032	0.08±0.09	0.03
Patient head (mSv)	220.27±221.17	198.60±193.45	331.12±274.96	
RCE (mGy)	658.54±321.43	547.54±217.54	991.53±370.06	<0.01
DAP (mGy-cm^2)	131 981±53 204	119 323±41 866	169 957±68 953	

Values are mean±SD.
DAP, dose area product; RCE, reported cumulative exposure.

There was no statistical difference in operator head exposure based on the type of procedure: 0.08 mSv (SD 0.22) in the diagnostic group and 0.05 mSv (SD 0.07) in the interventional group. When compared with doses measured on the inside of the protective skullcap, there was a statistically significant reduction in the amount of radiation received by the operator's skull (overall means 0.005±0.016 mSv inside vs 0.08±0.19 mSv outside the skull cap; $p<0.01$). The same was true across the two types of procedures (for diagnostic: 0.087±0.22 mSv outside vs 0.005±0.016 mSv inside; for interventional: 0.05 ±0.07 mSv outside vs 0.006±0.016 mSv inside).

Cranial exposure to the circulating nurse was measured by the electronic dosimeter placed on the right temporal scalp. Mean radiation exposure was 0.03±0.06 mSv (overall), 0.012 ±0.032 mSv (diagnostic), and 0.08±0.09 mSv (interventional).

Factors associated with patient cranial radiation exposure

For diagnostic procedures, fluoroscopy time was not significantly correlated with radiation exposure to the patient's head (Spearman r=0.42, p=0.08) but was significantly correlated with RCE to the patient (Spearman r=0.59, p=0.010) and DAP (Spearman r=0.68, p=0.002). Patient's cranial entrance exposure also correlated significantly with RCE (Spearman r=0.56, p=0.02) and DAP (Spearman r=0.47, p=0.05). For interventional procedures, patient's cranial entrance exposure was not correlated with RCE (Spearman r=0.37, p=0.47).

Factors associated with staff cranial radiation exposure

The correlation between fluoroscopy time and cranial radiation exposure to the circulating nurse was 0.45 (p=0.06) in diagnostic procedures. There was no significant correlation between fluoroscopy time and cranial radiation exposure to the operator (p=0.77). The correlation between nurse exposure and patient cranial exposure was r=0.57 (p=0.01), and RCE was r=0.45 (p=0.06). For interventional procedures, operator head exposure correlated significantly with RCE (r=−0.88, p=0.02) but not with DAP (r=−0.58, p=0.23).

DISCUSSION

Interventional radiological procedures carry a risk of radiation induced injuries to the skin, brain, and lens of the eye.[1 6 11 14 16 17 21 32–35] While recent advances in technology have significantly reduced occupational radiation exposures,[35] fluoroscopically guided procedures remain a high risk for radiation exposure.[36] In interventional procedures, entrance skin dose to the patient can frequently reach values high enough to cause injuries such as erythema or temporary epilation.[34] While maximum entrance skin dose during diagnostic procedures is likely to remain below the deterministic threshold for skin injuries, the same is not true for interventional procedures. Similar data on supporting staff in the angiography suite are scarce. The only established risk factor for brain tumors is ionizing radiation exposure to the cranium.[4 20 22 23 35] Studies show that irrespective of the dose, cranial irradiation increases the risk of developing meningiomas by up to 10-fold.[22 28] A recent study gave an alarming account of nine interventional cardiologists and radiologists developing left hemispheric malignancies after cumulative years of occupational radiation exposure.[21] Similarly, the risk of developing posterior lens opacities is significant.[16 17] In fact, the yearly exposure limit of 150 mSv to the lens was recently lowered by almost 8-fold to 20 mSV by the International Commission on Radiological Protection, reflecting recent epidemiological data.[26] While wearing leaded glasses is becoming a standard practice at many centers, there has not been a conclusive study to demonstrate the utility of cranial protection in neurointerventional suites. The only study addressing occupational cranial exposure comes from the interventional cardiology literature, was done in an experimental setting, and is almost a decade old.[15] To our knowledge, this is the first study to prospectively collect cranial radiation exposure data on patient and participating staff during neurointerventional procedures in real time.

In the present study, a ceiling suspended protective shield effectively blocked radiation scatter exposure to the operator side of the patient from 6.59 mSv (mean RCE of 658.54 mGy or 6.59 mSv, considering weighting factor for the brain as 0.01 in accordance with the International Commission on Radiological Protection) to 0.0017 mSv to the operator. However, despite excellent protection from the shield, mean cranial radiation exposure to the operator still measured 0.08 mSv. This is probably due to the fact that the head of the operator is not always behind the protective shield and that secondary scatter may reach the head.[15] Wearing the protective skullcap eliminated this exposure (0.005 mSv). Although as a single event an exposure of 0.08 mSv may not be significant, at high volume centers, with over five studies per day, this could amount to 150 mSv of cumulative exposure per year (thus far exceeding the deterministic threshold for the lens[26]). It is interesting to note that despite a protective shield on the anesthesia side, the circulating nurse was still exposed to a mean of 0.03 mSv cranial radiation per procedure. Thus, even the circulating nurse would have received almost 39 mSv of cumulative exposure per year.

Our study suggests that a modern neurointerventional suite is safe when equipped with proper protective shields and personal gear. However, cranial exposure is not completely eliminated with existing protective devices and the addition of a protective skullcap eliminates this exposure to both the operator and support staff. We therefore strongly suggest routine use of a protective skullcap.

Contributors MOC: conception and design, or analysis and interpretation of the data, drafting the article or revising it critically for important intellectual content, and final approval of the version to be published. DS and AB: collection of data. CM-K: statistical analysis and interpretation of the data. CLT: conception and design, drafting the article, or revising it critically for important intellectual content.

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Competing interests None.

Ethics approval

Provenance and peer review Not commissioned; externally peer reviewed.

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