Patient radiation exposure during diagnostic and therapeutic interventional neuroradiology procedures

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ABSTRACT

Purpose Increasing in number and complexity, interventional neuroradiology (INR) procedures are becoming an important source of radiation exposure for patients. In accordance with the ALARA principle, radiation exposure during INR procedures should be curtailed as much as possible while reaching successful treatment outcomes. Moreover, the extent of radiation exposure should be one outcome measure used to assess new technologies and procedural efficacy, and training programs should include techniques for exposure limitation. This study provides a methodology and preliminary data to assess radiation exposure during different INR procedure types.

Materials and methods All patients undergoing endovascular procedures in two biplanar dedicated neuroangiography suites at a major academic medical center were monitored according to procedure type, pathological indication, fluoroscopy time and machine-generated patient dose estimates between April 2006 and July 2008.

Results 1678 patients underwent cerebral arteriography during the study period. Women (62.1%) accounted for the majority of patients, but men (38.9%) were more likely to undergo an interventional procedure than women (32.8%). Diagnostic studies accounted for 64.9% of procedures. Variable exposures were found between diagnostic and interventional procedures. Exposure differed depending on indications for the procedure and procedure type.

Conclusion Radiation exposure is an increasingly important consideration in the development of minimally invasive neurological procedures including cerebral angiography and INR. The type of procedure and lesion type allow the practitioner to estimate radiation exposure. Such information informs the clinical decision making process. Normative data should be collected and used for comparison purposes as one measure of technical and procedural success.

Recently, the volume of interventional neuroradiology (INR) procedures has increased.[1] This increase is attributable to both technological advancements and evidence favoring endovascular techniques over conventional surgery.[2–4] The endovascular approach has successfully been adopted in the treatment of arteriovenous malformations (AVMs), fistulas, tumors, extracranial and intracranial atherosclerosis, and acute ischemic stroke, among others.[5] Benefits of endovascular procedures include lower morbidity and mortality, lower cost and shorter length of hospital stay.[6] However, these endovascular procedures expose patients to potentially significant amounts of radiation with inherent risks. Specifically, deterministic effects including skin epilation, erythema and desquamation have been observed following INR procedures when doses exceed 3 Gy, 6 Gy and 15 Gy, respectively.[7 8] Guidelines from non-medical radiation safety literature suggest that deterministic effects begin at estimated doses of >15 mSv.[9] Additionally, INR procedures, like all sources of radiation exposure, can cause stochastic risks, the most common and significant of which is cancer.[10]

As endovascular technology evolves and its uses expand, it is important to understand patient exposure to ensure patient safety. Recent studies have reported typical radiation exposure in phantoms and in small groups of patients undergoing subsets of INR procedures.[11–15] Little research to date has investigated values for radiation exposure during a variety of INR procedures in large numbers of patients. Furthermore, there are currently no standard reference values to guide neurointerventionalists concerning exposure encountered by patients during INR procedures using contemporary equipment.

This study retrospectively examines patient records for radiation exposure during a full complement of INR procedures performed by three operators at a major academic medical center over a 2-year period. This work aims to provide preliminary data for current patient exposure and to assist operators at other institutions to predict patient exposure. Moreover, these data may permit operators to evaluate their practices to identify those procedures or patients for which radiation exposure is expected to exceed normative levels.

MATERIALS AND METHODS

Recorded data

Machine-generated estimated patient exposure or doses were recorded between April 2006 and July 2008. Fluoroscopy time and dose area product (DAP) or skin absorbed dose (SAD) were recorded for each procedure by a radiology technologist at the conclusion of the procedure.

Patient age and sex were also recorded for each procedure. A procedure was excluded if any information was missing. One thousand six hundred and seventy-eight procedures were examined, 1088 (64.8%) of which had complete data sets. The most common reason for exclusion was incomplete or missing radiation estimate or fluoroscopy time recording (32.0%), a result of the lack of prospective standardization in data collection for this retrospective study. Seven hundred and forty-four data

points were analyzed from room A with DAP recorded. From room B, 322 data points were analyzed with SAD recorded, and 22 were analyzed with DAP recorded. One thousand and sixty-four (97.8%) procedures were performed by one of three clinicians.

Equipment

Room A contains a Philips Integris V C-arm biplane system (Philips Medical Systems, Amsterdam, The Netherlands) that has been in service since 1998. This device contains 12-inch image intensifiers. Room B contains a Siemens Axiom Artis dBA C-arm biplane system (Siemens Medical Solutions, Erlangen, Germany) with 40 cm×30 cm flat panel image receptors that has been in service since 2006. Both systems utilize heavy copper filtration with ranges of 4–5 mm Al HVL at 60–80 kVp. Each system has proprietary acquisition equipment and OEM software. Fluoroscopy frame rates are operator controlled and adjusted based on the ALARA principle.[16] Most angiographic acquisitions were performed at a rate of 2 fps or a variable frame rate. In certain uncommon circumstances for assessment of high-flow lesions, 6–7.5 fps frame rates were used. The duration of acquisitions averaged 10 s, with most falling within 8–12 s.

Dose and exposure measurement methodology

The Philips equipment assesses exposure in DAP (Gy-cm^2), while the Siemens equipment estimates exposure in DAP (Gy-cm^2) or dose in SAD (mGy). Estimated dose (ED) can be calculated from the DAP by several published methods.[17–20] ED calculations are based on the previously reported DAP–ED conversion factor range of 0.022–0.044 mSv Gy^{-1} cm^{-2}.[18] We employ such a range to ensure our conversions reflect the variable applied potential and filtration in our rooms.

Procedures

Procedures in this study were aggregated into 16 groups listed below.

Diagnostic

Any procedure in which angiography was performed without attempting intervention (ie, embolization, revascularization, etc). This category was further subdivided to more accurately characterize the procedure.

Follow-up. A diagnostic procedure performed on a patient with a known lesion based upon prior cross-sectional imaging or prior angiography.

Intracranial Hemorrhage (ICH). A diagnostic procedure performed on a patient with acute intracranial bleeding, either subarachnoid, subdural or intraparenchymal.

Investigatory. A diagnostic procedure performed on a patient without a known lesion with an abnormal clinical examination or a prior unexplained ICH without radiographic evidence of a lesion.

Post-Op. A diagnostic procedure performed on a patient to verify the success of an operation (ie, clipping, surgical excision, etc).

Stereotactic. A diagnostic procedure performed on a patient for the purposes of radiosurgery planning.

Ischemia. A diagnostic procedure performed on a patient who has clinical or radiographic signs of ischemia yet no endovascular intervention was performed (ie, fibrinolysis, mechanical thrombectomy, angioplasty, etc).

Balloon Test Occlusion (BTO). Any diagnostic procedure in which a BTO was performed.

Wada. Any diagnostic procedure in which provocative anesthetic testing was performed.

Table 1 Patient characteristics for each room and in aggregate

Room	Type	Gender	n	% Gender	Mean age (SD)
A	Diagnostic	Female	300	65.4	51.9 (17.8)
		Male	159	34.6	49.6 (17.5)
		Total	459	100.0	51.1 (17.3)
	Interventional	Female	166	58.2	53.5 (17.8)
		Male	119	41.8	47.7 (22.0)
		Total	285	100.0	51.1 (19.8)
B	Diagnostic	Female	145	62.2	53.7 (16.1)
		Male	88	37.8	48.1 (17.2)
		Total	233	100.0	51.6 (16.6)
	Interventional	Female	51	57.3	51.1 (16.5)
		Male	38	42.7	51.9 (20.3)
		Total	89	100.0	51.5 (8.2)
Total		Female	662	62.1	52.6 (17.3)
		Male	404	37.9	48.9 (18.3)
		Total	1066	100.0	51.2 (18.2)

Spinal. Any diagnostic procedure that included spinal angiography.

Interventional

Any procedure in which a therapeutic intervention was completed or attempted. These data were divided into specific subgroups for accurate characterization.

Cerebrovascular Structural Lesion (Aneurysm, Arteriovenous Malformation, Fistula, Tumor, Vein of Galen Malformation). Any procedure in which a patient with a known vascular lesion was treated or in which a vascular occlusion procedure was attempted.

Acute Ischemic Stroke. A patient who arrived with an acute ischemic stroke, with the intention of giving fibrinolytic or vasodilator therapy.

Vasospasm. A patient with symptomatic vasospasm causing delayed ischemic neurological deficits who received vasodilator therapy or balloon angioplasty.

Sclerotherapy, Vertebroplasty. Any patient in which percutaneous injection therapy was performed.

Spinal. Any interventional procedure performed in the spinal vasculature.

RESULTS

The average patient age and sex distribution were similar for pooled diagnostic and interventional procedures for each room (table 1). Women accounted for the majority of patients, but men (38.9%) were more likely to undergo an interventional procedure than women (32.8%).

Radiation dose or exposure for pooled diagnostic and interventional procedures are presented in table 2. Radiation dose or exposure and total fluoroscopy time for diagnostic procedures in

Table 2 Exposure and dose results by procedure type

Procedure type	n	DAP (SD) (Gy-cm^2)
Room A exposure by procedure		
Diagnostic	432	102.5 (43.5)
Interventional	311	167.3 (110.2)
Procedure type	**n**	**SAD (SD) (mGy)**
Room B dose by procedure		
Diagnostic	226	233 995 (445.4)
Interventional	94	89 2292.3 (1666.8)

DAP, dose area product; SAD, skin absorbed dose.

rooms A and B are presented in table 3, respectively. Additionally, table 3 contains ED calculations for room B. Table 4 contain comparisons of caseloads, dose or exposure averages, and fluoroscopy time averages by the three operators for rooms A and B. Among diagnostic procedure subtypes, investigatory and follow-up indications tended to have doses or exposures near the mean for all diagnostic procedures while BTO, ICH and ischemia subtypes exceeded the overall mean. Postoperative and stereotactic studies required lower radiation doses or exposures, and Wada tests exposed patients to significantly less radiation than any other diagnostic angiographic procedure types. Room B procedures with DAP recorded were excluded from these tabulations due to their small number (n=22).

Radiation dose or exposure and total fluoroscopy time for interventional procedures, as well as pooled diagnostic and spinal diagnostic data, for rooms A and B are presented in table 5. Radiation doses or exposures for interventional procedures varied with intervention subtype. Substantially high doses and exposures occurred in treatment for aneurysm, AVM, dural fistulas, acute ischemic stroke and tumor, as well as revascularization and spinal diagnostic and spinal interventional procedures. Doses during vertebroplasty averaged levels near those for pooled diagnostic procedures, and sclerotherapy, vasospasm treatment and vein of Galen treatments had far lower rates. Again, room B procedures with DAP recorded were excluded.

Direct comparison of the two rooms was performed using the pooled diagnostic procedure data from room B recorded as DAP. With analysis by unpaired t test, room B (n=22, mean=83.27 Gy-cm^2) had significantly lower patient doses than room A (n=432, mean=102.36 Gy-cm^2) (p=0.031). Comparable ED conversion ranges for room B procedures with DAP recordings and room A procedures were 1.8–3.7 mSv and 2.3–4.5 mSv, respectively. The two rooms had similar procedure profiles, despite the comparatively smaller number from room B.

Table 3 Radiation exposure and exposure time during diagnostic procedures

Sub-type	n	DAP (SD) (Gy-cm^2)	mSv	Time (SD) (min)
Room A diagnostic procedures; room A with measured DAP and converted ED range				
BTO	3	111.3 (38.9)	2.4–4.9	26.2 (10.3)
Investigatory	14	95.1 (26.8)	2.1–4.2	9.4 (3.1)
Follow-up	230	95.1 (38.3)	2.1–4.2	10.9 (7.4)
ICH	126	122.6 (42.5)	2.7–5.4	12.7 (5.6)
Ischemia	21	112.8 (54.7)	2.5–5.0	10.6 (4.4)
Postop	26	79.1 (50.2)	1.7–3.5	8.7 (8.3)
Stereotactic	12	68.2 (41.8)	1.5–3.0	6.2 (3.1)
Total	432	102.4 (43.4)	2.3–4.5	11.2 (6.9)

Procedure	n	SAD (SD) (mGy)	Time (SD) (min)
Room B interventions; room B with SAD			
Diagnostic—pooled	227	995.0 (445.4)	9.9 (4.8)
Diagnostic—spinal	6	1089.2 (725.4)	14.4 (15.5)
INT—aneurysm	28	3135.5 (1459.0)	68.2 (28.1)
INT—AVM	18	2044.4 (1224.5)	36.4 (24.5)
INT—fistula	4	2696.0 (2863.6)	80.9 (48.9)
INT—revascularization	14	2312.1 (2049.6)	40.9 (34.1)
INT—spinal	1	943.0 (0)	20.5 (0)
INT—stroke	6	2896.7 (2729.8)	44.4 (41.5)
INT—tumor	5	1508.6 (295.0)	36.6 (23.5)
INT—vasospasm	13	1213.5 (734.1)	17.7 (10.9)
Total	322	1372.0 (1137.9)	20.2 (24.4)

BTO, balloon test occlusion; DAP, dose area product; ICH, intracranial hemorrhage; SAD, skin absorbed dose.

Table 4 Caseload, dose or exposure, and fluoroscopy time averages by the three operators

Clinician	n	DAP (SD) (Gy-cm^2)	mSv	Time (SD) (min)
Room A comparisons by operator; room A with DAP and converted ED range				
1	230	140.9 (95.1)	3.1–6.2	21.3 (13.9)
2	342	128.8 (80.6)	2.8–5.7	16.8 (12.7)
3	171	117.4 (76.1)	2.6–5.2	16.5 (15.7)

Clinician	n	SAD (SD) (mGy)	Time (SD) (min)
Room B comparisons by operator; room B with SAD			
1	25	1331.0 (942.9)	22.0 (17.9)
2	76	1256.5 (847.4)	16.8 (19.0)
3	220	1414.1 (1243.6)	21.1 (26.7)

DAP, dose area product; SAD, skin absorbed dose.

The data in tables 3 and 4 also indicate the predictability of radiation doses and exposures between different procedure types. Among diagnostic procedures, spinal cases had the highest SD of all types examined. Outside these procedures, the remaining diagnostic subtypes generally had less variability in SD than interventions. Interventions for vasospasm, vein of Galen malformations and sclerotherapy had the smallest standard deviations. The most variable interventional procedures were treatments of fistulas, AVMs, aneurysms, spinal lesions and revascularization. Stroke, tumor and vertebroplasty interventions demonstrated standard deviations similar in range to pooled diagnostic data.

Table 5 Radiation exposure and exposure time during interventional procedures, pooled diagnostic procedures and spinal diagnostic procedures

Procedure	n	DAP (SD) (Gy-cm^2)	ED (mSv)	Time (SD) (min)
Room A interventions; room A with measured DAP and converted ED range				
Diagnostic—pooled	432	102.4 (43.4)	2.3–4.5	11.2 (6.9)
Diagnostic—spinal	27	294.9 (217.9)	6.5–13.0	29.7 (13.5)
INT—aneurysm	60	172.3 (67.7)	3.8–7.6	36.5 (15.2)
INT—AVM	74	160.9 (87.9)	3.5–7.1	27.4 (14.5)
INT—fistula	8	195.6 (63.8)	4.3–8.6	44.5 (16.8)
INT—revascularization	20	174.1 (72.4)	3.8–7.7	26.7 (10.3)
INT—sclerotherapy	9	6.1 (8.6)	0.1–0.3	2.9 (2.2)
INT—spinal	19	197.8 (136.6)	4.4–8.7	28.0 (16.5)
INT—stroke	22	163.3 (62.5)	3.6–7.2	24.6 (14.4)
INT—tumor	33	182.5 (63.3)	4.0–8.0	27.2 (11.6)
INT—vasospasm	30	84.1 (36.0)	1.9–3.7	14.4 (12.0)
INT—vein of Galen	3	75.7 (5.0)	1.7–3.3	45.0 (20.6)
INT—vertebroplasty	7	109.3 (62.7)	2.4–4.8	18.7 (4.1)
Total	744	129.6 (84.8)	2.9–5.7	18.1 (14.0)

Procedure	n	SAD (SD) (mGy)	Time (SD) (min)
Room B interventions; room B with SAD			
Diagnostic—pooled	227	995.0 (445.4)	9.9 (4.8)
Diagnostic—spinal	6	1089.2 (725.4)	14.4 (15.5)
INT—aneurysm	28	3135.5 (1459.0)	68.2 (28.1)
INT—AVM	18	2044.4 (1224.5)	36.4 (24.5)
INT—fistula	4	2696.0 (2863.6)	80.9 (48.9)
INT—revascularization	14	2312.1 (2049.6)	40.9 (34.1)
INT—spinal	1	943.0 (0)	20.5 (0)
INT—stroke	6	2896.7 (2729.8)	44.4 (41.5)
INT—tumor	5	1508.6 (295.0)	36.6 (23.5)
INT—vasospasm	13	1213.5 (734.1)	17.7 (10.9)
Total	322	1372.0 (1137.9)	20.2 (24.4)

Pooled diagnostic data do not include diagnostic spinal cases.
DAP, dose area product; SAD, skin absorbed dose.

DISCUSSION

INR procedures can potentially cause considerable radiation exposure with the potential for both stochastic and deterministic effects. Therefore it is important to characterize risks and monitor patients undergoing these procedures. Exposure has continued to increase as interventional methods are used to treat more complex lesions, protocol demands increase and more studies utilize biplane imaging.[11] Calculation of radiation exposure incurred with such procedures has proved difficult to generalize due to inter-institutional differences in procedure complexity, equipment and practitioner skill and technique. This study aimed to offer data characterizing various diagnostic cerebral and interventional neuroradiological procedures to provide reference points for other institutions and their practitioners.

Lack of standardization among hospitals, physicians and machine vendors results in multiple methods used for measuring patient x-ray dosage. Measurement units include DAP, ED, fluoroscopy time, skin dose and air kerma. Devices at our institution calculate fluoroscopy time, DAP and SAD; thus some of these data are readily comparable with previously published results for general cerebral angiography. DAP values have been observed to correlate well with measured SAD and ED.[21] Previous DAP values range from 53 to 168 Gy-cm^2.[11 17 22–26] During these procedures, the mean DAP from room A was within this range at 129.6 Gy-cm^2, as was the mean in room B (83.3 Gy-cm^2) for the 22 procedures for which DAP was recorded. The mean SAD in room B was 995 mGy, also within the range (350–4100 mGy) of published reports.[7 12 26 27] Concordance of these data with those in previously published reports suggests that our findings provide at least approximate applicability to INR procedures in other departments.

The major goal of this study was to provide a general outline of radiation doses to be expected for various INR procedures. While interventional procedures typically expose patients to larger doses, some diagnostic studies can result in surprisingly high patient doses. For example, using information gleaned from examination of interventional procedures, we can recommend that practitioners practice vigilance in following the ALARA principle while performing diagnostic studies for patients with high-flow vascular lesions like AVMs and fistulas when high frame rate acquisitions are used to discern lesion characteristics. Conversely, some procedures result in much lower risk to patients of adverse effects from radiation. One case is vasospasm treatments, which resulted in relatively small doses of radiation, so the practitioner may be less hesitant, should the need present itself, for additional angiography runs. Additionally, dosage predictability varies according to procedure type. As an illustration, the dose caused by sclerotherapy will be quite predictable, while AVM embolization doses can vary substantially. This variability in dose predictability must also be considered. Ultimately, the angiographer must make active decisions to limit radiation exposures caused by INR procedures.

Limitations in this study are similar to those identified in previous work. Numerous previous studies have reported radiation doses during diagnostic cerebral angiography, yet unique institutional patterns and operator preferences cause difficulty in making radiation dose comparisons between facilities for INR procedures. Indeed, our inability to more substantially compare results between our two rooms illustrates this limitation. Prospective planning of standardized data collection would have afforded more complete data for analysis. Additionally, more variables could have been recorded, such as number of acquisitions, frame rates and the number of vessels examined. Furthermore, the two angiography suites have such different exposure tendencies, comparison between them is limited. Such differences are likely the result of disparate exposure limiting technologies and operators with different tendencies favoring certain suites.

Several physician disciplines now perform INR procedures. Uniform training in the use of radiant energy is needed for physicians to optimize the application of the ALARA principle. Technological development should decrease procedure time and radiation exposure as it increases ease of use. However, a substantial role remains for the interventionalist to limit exposure. Moreover, the field would benefit from standardization to assess both current treatment methods and emerging technologies used in INR procedures for ease of application and efficacy. Robust tracking of exposure data, such as with a multicenter database, would help the field monitor radiation burdens caused by its procedures and guide improvements in clinician training and delivery of care. Given the duration of these procedures, there exists a risk of significant harm if radiation exposure is not well controlled. More research will be important and is warranted.

CONCLUSION

The recent increase in number and complexity of INR procedures results in increased patient radiation exposure. Each institution and practitioner must ultimately investigate their own unique practices to control unnecessary radiation exposure according to the ALARA principle. To best avoid serious deterministic and stochastic risks of x-ray fluoroscopy and angiography, normative exposure data should be collected within a robust, generalizable protocol so that practice guidelines can be established.

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