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Original Paper

Radiation Exposure during Neurointerventional Procedures in Modern Biplane Angiographic Systems: A Single-Site Experience

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Keywords
Endovascular surgical neuroradiology · Interventional neuroradiology · Radiation exposure

Abstract

Background and Purpose: Per the ALARA principle, reducing the dose delivered to both patients and staff must be a priority for endovascular therapists, who should monitor their own practice. We evaluated patient exposure to radiation during common neurointerventions performed with a recent flat-panel detector angiographic system and compared our results with those of recently published studies. ***Methods:*** All consecutive patients who underwent a diagnostic cerebral angiography or intervention on 2 modern flat-panel detector angiographic biplane systems (Innova IGS 630, GE Healthcare, Chalfont St Giles, UK) from February to November 2015 were retrospectively analyzed. Dose-area product (DAP), cumulative air kerma (CAK) per plane, fluoroscopy time (FT), and total number of digital subtraction angiography (DSA) frames were collected, reported as median (interquartile range), and compared with the previously published literature. ***Results:*** A total of 755 consecutive cases were assessed in our institution during the study period, including 398 diagnostic cerebral angiographies and 357 interventions. The DAP (Gy × cm^2), fontal and lateral CAK (Gy), FT (min), and total number of DSA frames were as follows: 43 (33–60), 0.26 (0.19–0.33), 0.09 (0.07–0.13), 5.6 (4.2–7.5), and 245 (193–314) for diagnostic cerebral angiographies, and 66 (41–110), 0.46 (0.25–0.80), 0.18 (0.10–0.30), 18.3 (9.1–30.2), and 281 (184–427) for interventions. ***Conclusion:*** Our diagnostic cerebral angiography group had a lower median and was in the 75th percentile of DAP and FT when compared with the published literature. For interventions, both DAP and number of DSA frames were significantly lower than the values reported in the literature, despite a higher FT. Subgroup analysis by procedure type also revealed a lower or comparable DAP.

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Introduction

Neurointerventional procedures are effective minimally invasive treatment options for various neurovascular conditions (intracranial aneurysm [1, 2], acute ischemic stroke [3, 4], arteriovenous fistula [AVF] or arteriovenous malformation [AVM], etc.). However, because of the complexity of the pathologies to be treated, there is a significant number of procedures requiring prolonged X-ray procedures or high-dose acquisitions, which can result in increased radiation exposure to the patients as well as staff members [5, 6], leading to potential deterministic and stochastic adverse effects [7].

The harmful consequences of radiation dose are a rising concern among physicians [8–12] as they face occupational exposure over their lifetime. A recent study showed a correlation between patient dose and occupational dose [13].

As defined by national and international organizations (European Commission Council Directive 97/43/EURATOM [14], International Commission on Radiological Protection [ICRP] [15]), radiation protection is based on 3 fundamental principles: justification, optimization (also known as ALARA), and dose limitation (applicable to occupational and public exposure).

The assessment of patient radiation doses during interventional procedures and their comparison with reference values has been recommended by several professional and regulatory organizations (ICRP, International Atomic Energy Agency [16], and European Commission) as an important component of the optimization process to guide implementation of dose reduction strategies and better control patient radiation exposure. Unfortunately, to date there are only few published radiation data for neurointerventional procedures using modern angiographic systems.

The goal of this study was to establish a baseline of radiation doses at a comprehensive neuroscience center that utilizes contemporary digital equipment for all the different types of neurointerventional procedures and compare them to those in the recently published literature.

Materials and Methods

This retrospective study was approved by the MetroWest IRB; informed written consent was waived.

All consecutive patients who underwent cerebral diagnostic angiography or endovascular treatment between February and November 2015 in our comprehensive stroke center were retrospectively enrolled. As a reference, our institution activity includes over 1,000 endovascular surgical neuroradiology procedures per year, performed by one of the 2 experienced endovascular neurointerventional radiologists on-site.

Procedures were categorized into 2 groups: cerebral angiography and neurointervention. The neurointervention group was further subdivided into 4 subgroups: (1) embolization of an AVF or AVM, (2) aneurysm embolization, (3) stroke mechanical thrombectomy, and (4) other types of neurointerventional procedures including carotid stenting, intracranial angioplasty and/or stenting, vasospasm treatment, vertebral stenting, microcatheter exploration, and tumor embolizations. All these procedures were performed in one of our 2 angiography biplane rooms (Innova IGS 630, GE Healthcare, Chalfont St Giles, UK) equipped with two 30 × 30 cm flat-panel detectors with 3-dimensional imaging and advanced imaging capabilities, such as cone beam computed tomography, and 3-dimensional roadmapping. Advanced exposure management allowed dynamic and automatic control of X-ray technique and automatic selection of additional copper filtration. Both systems provide built-in dosimetry indications per exam. Default settings used were fluoroscopy 7.5 fps and multi-segment digital subtraction angiography (DSA) with variable framerate (4, 2, or 1 fps for the different segments). Finally, large display monitors were used and reduced the need for magnification [17].

Both operators use in routine some of the dose reduction strategies described by Pearl and colleagues [18, 19], which comprises of the use of fluoroscopy instead of DSA for the femoral access evaluation, the use of a low fluoroscopy framerate (7.5 fps) and variable-framerate DSA, recording of the radiation data, and for follow-up studies the re-use of sequences from previous procedures to minimize the use of DSA for evaluation of the aortic arch. In case of high-flow lesions, a higher DSA framerate is selected.

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Table 1. Literature review on radiation during cerebral angiography and cerebral interventions (comparison with the results from the current study)

Reference (first author)	Year	*n*	DAP, Gy × cm^2	*p*	CAK, Gy	FT, min	Number of DSA frames	Details
Cerebral angiography								
This study	2017	398	43.1 (33.3–59.7)		FRT: 0.26 (0.20–0.33) LAT: 0.09 (0.07–0.13) FRT+LAT: 0.35 (0.28–0.45)	5.6 (4.2–7.5)	245 (193–314)	FPD only
Brambilla [34]	2004	188	158[a] (198[b])	<0.01	–	13.7[a] (17.5[b])	–	
Verdun [35]	2005	91	107[a] (124[b])	<0.01	–	–	–	
Aroua [36]	2007	91	121[a] (125[b])	<0.01	–	12.6[a] (2–85[c])	679[a] (32–5,486[c])	
Vano [22]	2008	72	(107[b])	–	–	(12[b])	(550[b])	
Bleeser [37]	2008	616	(71[b])	–	–	–	–	
Sarycheva [25]	2010	138	86[a] (13–313[c])	<0.01	–	1.5[a] (0.3–9.9[c])	343[a] (60–1,125[c])	
Alexander [27]	2010	432	102.4[a]	<0.01	–	11.2[a]	–	image intensifier only; no DAP values on FPD
Kien [38]	2011	1,786	152 (229[b])	<0.01	–	8.9 (14[b])	326 (472[b])	cerebral angiography diagnostic: 3 or more axes
D’Ercole [39]	2012	113	131 (180[b])	<0.01	–	8.5 (12.3[b])	220 (317[b])	
Söderman [26]	2013	174	47 (28–76)	<0.01	FRT: 0.21 (0.13–0.37) LAT: 0.06 (0.03–0.11)	6 (4–9)	278 (173–402)	FPD only
Chun [40]	2014	439	136.6[a] (154.2[b])	<0.01	–	12.6[a] (14[b])	251[a] (273[b])	FPD only; control excluded; image frames
Chung [24]	2015	42–50[d]	–	–	FRT+LAT: System 0: 1.525[a] System 1: 1.499[a] System 2: 1.184[a] System 3: 0.973[a]	–	–	system 0: image intensifier; systems 1, 2, 3: FPD
Schneider [19]	2016	200	78.6 (n/a)	<0.01	FRT+LAT: 0.653 (n/a)	6.6	–	adults only; FPD
Neurointerventional procedures								
This study	2017	357	66.0 (40.7–110.8)	–	FRT: 0.46 (0.25–0.80) LAT: 0.18 (0.10–0.30) FRT+LAT: 0.64 (0.37–1.10)	18.3 (9.1–30.2)	281 (184–427)	33 AVF/AVM embolization, 71 aneurysm embolization, 73 stroke mechanical thrombectomy, 180 other interventions
Verdun [35]	2005	52	335[a] (352[b])	<0.01	–	–	–	therapeutic obstruction (coiling) during the treatment of AVM, AVF, intracranial aneurisms, tumors, or hemorrhagic lesions
Aroua [36]	2007	91	121[a] (125[b])	<0.01	–	36.5[a] (3.3–134[c])	760[a] (60–3,348[c])	therapeutic obstruction (coiling) during the treatment of AVM, AVF, intracranial aneurisms, tumors, or hemorrhagic lesions
Suzuki [41]	2008	103	257[a]	<0.01	–	67.3[a]	883[a]	cerebral embolization (AVM, aneurysm, AVF)
Alexander [27]	2010	311	167.3[a]	<0.01	–	–	–	image intensifier only; no DAP values on FPD
Sarycheva [25]	2010	66	145[a] (20–548[c])	<0.01	–	4.1[a] (1.4–26.2[c])	249[a] (85–1,572[c])	therapeutic
D’Ercole [39]	2012	72	352 (487[b])	<0.01	–	34.6 (46.3[b])	559 (717[b])	cerebral embolization (aneurysm or AVM)
Vano [5]	2013	year 2009: *n* = 90; year 2010: *n* = 92	year 2009: 242 (386[b]); year 2010: 270 (392[b])	<0.01	year 2009: FRT+LAT: 2.4 (3.9[b]) year 2010: FRT+LAT: 2.5 (3.3[b])	–	–	cerebral embolization; cumulative skin dose; FPD
Söderman [26]	2013	138	109 (67–196)	<0.01	FRT: 0.68 (0.38–1.35) LAT: 0.21 (0.10–0.45)	12 (5–16)	464 (299–845)	FPD; 4 AVM, 38 aneurysms, 45 stroke, 51 other interventions
Kahn [42]	2016	30	150[a]	<0.01	FRT+LAT: 1.650[a]	51.1[a]	–	aneurysm coiling, balloon angioplasty, stroke intervention, tumor and AVM embolization; reduced dose group

Table 1 (continued)

Reference (first author)	Year	*n*	DAP, Gy × cm^2	*p*	CAK, Gy	FT, min	Number of DSA frames	Details
AVF/AVM embolization								
This study	2017	33	149.6 (114.7–206.4)	–	FRT: 0.99 (0.65–1.55) LAT: 0.56 (0.28–0.75) FRT+LAT: 1.65 (0.96–2.35)	57.0 (36.4–76.1)	706 (522–904)	AVF/AVM embolization
Miller [43]	2003	177	339^{a} (39.8–1,351^{c})	<0.01	FRT+LAT: 3.79^{a} (0.04–13.410^{c})	92.5^{a} (2.6–313.7^{c})	1,037^{a} (71–2,654^{c})	AVM embolization
Miller [20]	2009		530^{d}	–	FRT+LAT: 6.00^{d}	135^{d}	1,500^{d}	AVM embolization
Alexander [27]	2010	74 8	160.9^{a} 195.6^{a}	>0.05 –	– –	36.5^{a} 44.5^{a}	– –	AVM; fistula; image intensifier only, no DAP values on FPD
Kien [38]	2011	370	269 (435^{b})	<0.01	–	38 (61^{b})	770 (1,410^{b})	AVM embolization
Kien [38]	2011	75	364 (726^{b})	<0.01	–	59 (82^{b})	770 (1,036^{b})	AVF embolization
Slater [44]	2014	44	338 (225–528)	<0.01	–	–	–	AVM embolization
Aneurysm embolization								
This study	2017	71	78.7 (59.5–111.9)		FRT: 0.71 (0.48–0.94) LAT: 0.29 (0.23–0.40) FRT+LAT: 1.04 (0.73–1.34)	25.7 (19.9–34.8)	300 (212–428)	aneurysm embolization
Miller [43]	2003	149	282.7^{a} (67.9–825.5^{c})	<0.01	FRT+LAT: 3.77^{a} (1.28–9.81^{c})	75^{a} (15.2–401.3^{c})	1,070^{a} (292–2,440^{c})	aneurysm embolization
Miller [20]	2009		360^{d}	–	FRT+LAT: 4.75^{d}	90^{d}	1,350^{d}	aneurysm embolization
Alexander [27]	2010	60	172.3^{a}	<0.01	–	36.5^{a}	–	aneurysm (image intensifier only, no DAP values on FPD)
Kien [38]	2011	1,034	235 (349^{b})	<0.01	–	37 (58^{b})	810 (1,199^{b})	aneurysm embolization
Kien [38]	2011	628	188 (272^{b})	<0.01	–	–	–	aneurysm embolization; FPD only
Chun [40]	2014	111	226.0^{a} (272.8^{b})	<0.01	–	52.9^{a} (61.1^{b})	241^{a} (276.0^{b})	endovascular coil; embolization of intracranial aneurysms; image frames; FPD
Slater [44]	2014	188	211 (130–328)	<0.01	–	–	–	cerebral aneurysm embolization
Ihn [45]	2016	371	179.0 (104.5–271.0)	<0.01	FRT+LAT: 2.80 (1.69–4.47)	44.5 (30.4–64.7)	412.5 (241.5–567.3)	aneurysmal coil embolization

Values are given as median (IQR) unless otherwise indicated. AVF, arteriovenous fistula; AVM, arteriovenous malformation; CAK, cumulative air kerma; DAP, dose-area product; DSA, digital subtraction angiography; FPD, flat-panel detector; FRT, frontal plane; FRT+LAT, cumulated on frontal and lateral plane; FT, fluoroscopy time; LAT, lateral plane; n/a, not available. ^{a} Mean. ^{b} Third quartile. ^{c} Range. ^{d} Dose reference level (based on 75th percentile) *p* value from nonparametric 1-sample sign test when referenced data provided as median and 1-sample *t* test when referenced data provided as mean.

Table 2. Number of procedures and patient characteristics by type of procedures and split by operator

	Number of procedures	Gender, *n* (%)		Age, years, mean ± SD (range)	Operator, *n* (%)	
		males	females		1	2
Cerebral angiography	398	213 (54)	185 (46)	60±16 (8–91)	243 (61)	155 (39)
Intervention	357	179 (50)	178 (50)	60±16 (17–94)	225 (63)	132 (37)
AVF/AVM embolization	33	16 (48)	17 (52)	48±11 (17–65)	23 (70)	10 (30)
Aneurysm embolization	71	28 (39)	43 (61)	58±14 (23–88)	45 (63)	26 (37)
Stroke mechanical thrombectomy	73	35 (48)	38 (52)	73±12 (43–94)	38 (52)	35 (48)
Other interventions	180	100 (56)	80 (44)	58±17 (17–90)	119 (66)	61 (34)
Total	755	392 (52)	363 (48)	60±16 (8–94)	468 (62)	287 (38)

For each procedure, the following data were collected: patient's demographics (sex, age), procedural details (operator, type of procedure, volume of contrast media, and radiation exposure).

The following indirect dose parameters were provided by the built-in software for both biplane angiographic systems: (1) Summed for both imaging planes (frontal and lateral chain): (a) cumulative dose-area product (DAP, the cumulative air kerma [CAK] multiplied by the exposed area, in Gy × cm^2); (b) CAK, the incident cumulative dose at the interventional reference point (IRP) without backscatter, in mGy; (c) fluoroscopy time (FT) in min; (d) number of DSA frames, with exclusion of number of cone beam computed tomography projections. (2) For each imaging plane: (a) CAK Frontal at IRP in mGy and (b) CAK lateral at IRP in mGy.

In principle, for a relevant comparison of radiation doses, DAP and air kerma should be analyzed based on body size. However, this is not required for cerebral procedures, as there is little variation in size when it comes to head anatomy [20]. Consequently, patients' weight and height were not collected.

In order to compare our radiation dose levels to published reference levels for cerebral diagnostic and interventional procedures, a PubMed search was performed from 2003 on. The radiation data for each procedure are summarized in Table 1. Flat-panel detector technology was also mentioned whenever this information could be retrieved from the publication, as significant reduction in radiation exposure (up to 30%) has been reported with this technology in comparison with older-generation image intensifiers [21].

Statistical analysis was done using Microsoft® Excel® 2010 (version 14.0.7165.5000) and Minitab® 17 statistical software (2010) (version 17.3.1; Minitab Inc.). This was an observational, nonrandomized study; therefore, the statistical analysis was based on descriptive statistical techniques. Categorical variables were presented as numbers and percentages and were compared using the χ^2 test. Continuous variables were described with mean, standard deviation, and range, and completed by median and interquartile range for non-normally distributed data as appropriate. The distribution of all continuous variables was assessed with the Shapiro-Wilk test for normality. Correlations were tested by linear and nonparametric Spearman's correlation tests as appropriate. DAP was compared with the literature using the nonparametric 1-sample sign test when referenced data were provided as median and 1-sample *t* test when referenced data were provided as mean. A 95% confidence level was used for all statistical calculations and a p value ≤0.05 was considered significant.

Results

A total of 831 procedures were performed during the inclusion period. When excluding the ones with incomplete datasets, a total of 755 procedures (91%) were included in the analysis, with the following procedural split: 53% cerebral angiography and 47% neurointerventions. In the interventional group, the repartition in subgroups 1, 2, 3, and 4 was 9, 20, 20, and 50%, respectively.

There was no significant difference in age or gender for cerebral angiography procedures (females 59.1 ± 17.0 years vs. males 60.8 ± 15.5 years, $p = 0.32$) and interventional procedures

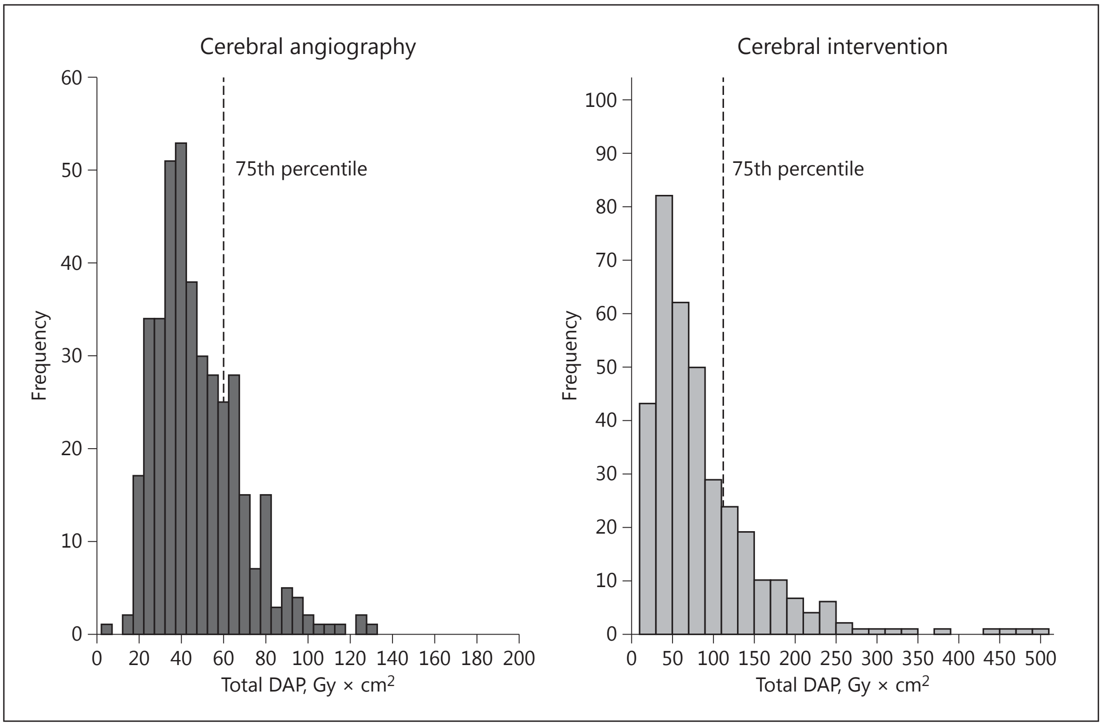
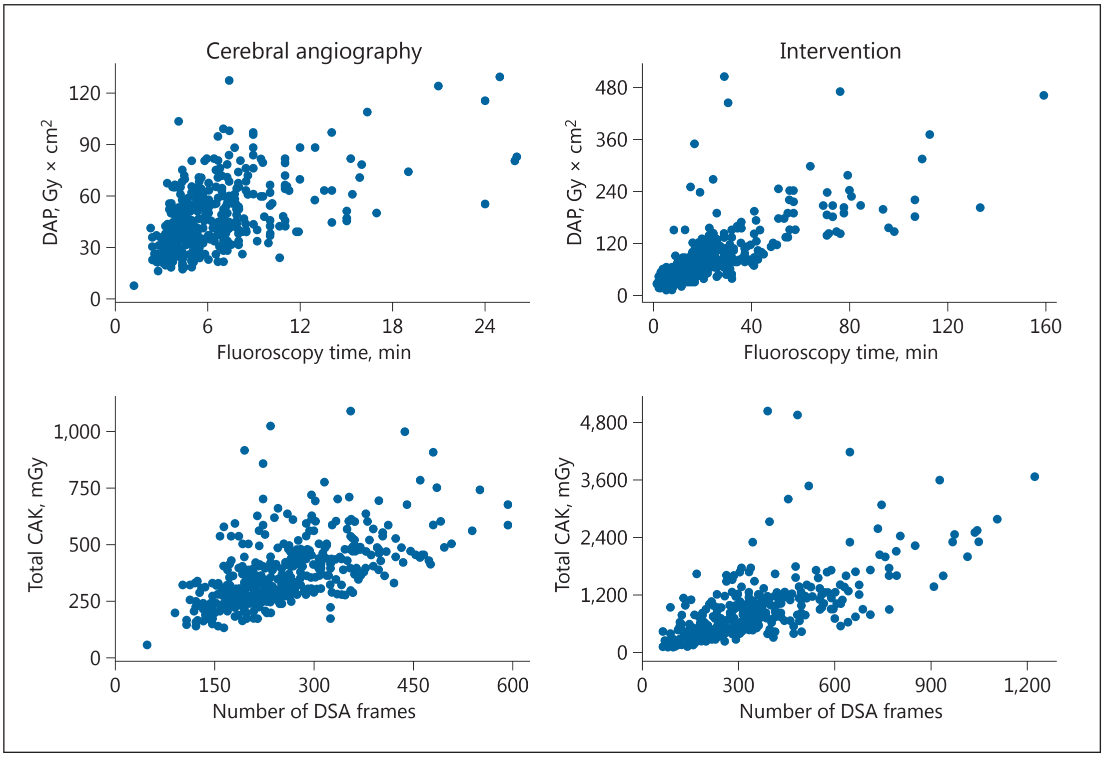


Fig. 1. Distribution of cumulative dose-area product (DAP) (Gy × cm^2) for cerebral angiography and cerebral intervention, with the third quartile represented by the dashed line.



Color version available online

Fig. 2. Scatter plot between dose-area product (DAP)/fluoroscopy time and cumulative air kerma (CAK)/number of digital subtraction angiography (DSA) frames for cerebral angiography and intervention.

Table 3. Radiation dose indicators for diagnostic cerebral angiography and cerebral intervention

	Diagnostic	Intervention				
	cerebral angiography	all interventions	AVF/AVM embolization	aneurysm embolization	stroke mechanical thrombectomy	other interventions
n	398	357	33	71	73	180
DAP, Gy × cm^2						
Mean ± SD	47.8±19.8	88.0±72.7	163.3±60.4	97.3±71.9	90.9±40.9	69.3±75.6
Median (IQR)	43.1 (33.3–59.7)	66.0 (40.7–110.8)	149.6 (114.7–206.4)	78.7 (59.5–111.9)	86.0 (59.7–109.9)	43.2 (30.4–77.7)
Range	7.5–130.1	10.8–505.6	64.6–316.3	25.0–459.9	34.2–240.0	10.8–505.6
CAK FRT, mGy						
Mean ± SD	275±120	607±564	1,163±634	834±570	575±296	428±538
Median (IQR)	257 (197–330)	460 (250–802)	994 (654–1,553)	707 (479–943)	460 (359–757)	267.5 (169–529)
Range	38–907	67–4,935	403–2,960	272–3,800	189–1,636	67–4,935
CAK LAT, mGy						
Mean ± SD	101±42	239±198	546±241	347±206	232±127	143±116
Median (IQR)	93 (70–128)	182 (102–298)	564 (278–746)	288 (234–404)	192 (147–290)	111 (73–172)
Range	0–273	0–1,235	225–962	76–1,235	87–673	0–750
CAK FRT+LAT, mGy						
Mean ± SD	376±149	846±713	1,709±835	1,180±765	807±397	572±581
Median (IQR)	351 (276–450)	639 (369–1,104)	1,653 (957–2,350)	1,037 (727–1,368)	719 (503–1,018)	384 (252–717)
Range	57–1,089	95–5,035	679–3,669	389–5,035	276–2,304	95–4,935
Total fluoroscopy time, 0.1 min						
Mean ± SD	6.5±3.6	24.4±22.8	58.2±26.4	33.9±27.1	22.7±12.5	15.0±14.9
Median (IQR)	5.6 (4.2–7.5)	18.3 (9.1–30.2)	57.0 (36.4–76.1)	25.7 (19.9–34.8)	19.9 (13.1–29.1)	10.1 (5.2–20.0)
Range	1.2–26	1.8–159.0	18.6–110.0	9.3–159.0	6.5–77.6	1.8–96.2
Total number of DSA frames						
Mean ± SD	259±92	338±208	702±254	330±154	385±130	255±163
Median (IQR)	245 (193–314)	281 (184–427)	706 (522–904)	300 (212–428)	359 (286–458)	206 (158–306)
Range	48–591	64–1,220	272–1,220	64–743	176–676	64–1,008
Volume of contrast media, mL						
Mean ± SD	55.4±21.5	74.1±41.9	95.2±33.8	90.8±44.3	89.7±33.5	57.4±38.6
Median (IQR)	55.0 (40.0–70.0)	70.0 (40.0–105.0)	100.0 (72.5–120.0)	85.0 (60.0–110.0)	90.0 (63.5–112.5)	45.0 (26.5–80.0)
Range	6.0–150.0	10.0–200.0	10.0–150.0	20.0–200.0	29.0–160.0	10.0–180.0

AVF, arteriovenous fistula; AVM, arteriovenous malformation; CAK, cumulative air kerma; DAP, dose-area product; DSA, digital subtraction angiography; FRT, frontal plane; FRT+LAT, cumulated on frontal and lateral plane; IQR, interquartile range; LAT, lateral plane; SD, standard deviation.

(females 59.6 ± 17.2 years vs. males 60.7 ± 15.0 years, $p = 0.53$). Except for AVF/AVM embolization, where the sample size is too small, there was no significant difference in gender and age between operators by type of procedure ($p > 0.05$). The population demographics are summarized in Table 2.

The collected radiation dose data were not normally distributed and highly skewed, with an asymmetric shape, as shown in Figure 1 ($p < 0.005$) representing histograms of DAP for cerebral angiography (398 procedures) and cerebral intervention (357 procedures) combined for both operators.

The distribution of DAP, other dosimetry indicators, and the volume of contrast media for diagnostic and therapeutic procedures for both operators are provided in Table 3.

There was a statistically significant difference between the median DAP and CAK among all the procedure types by the Kruskal-Wallis test ($p < 0.001$). Of the analyzed interventional procedures, AVF/AVM embolization had the highest median DAP and CAK (149.6 Gy × cm^2 and 1,653 mGy, respectively).

Spearman correlations were run to further assess the monotonic relationship between DAP (CAK, respectively) and total FT (number of DSA frames, respectively) for cerebral angiography and neurointerventions (Fig. 2). For cerebral angiography, the correlations were positive, moderate to strong ($0.53 < \rho < 0.70$), while for neurointerventions they were positive, strong to very strong ($0.77 < \rho < 0.881$). All correlations were statistically significant ($p < 0.01$).

Discussion

The main goal of this retrospective and observational study was to characterize the patient-received radiation dose levels during neurointerventional procedures, in a comprehensive center equipped with modern biplane angiographic systems, with representative demographics and procedural mix, and excluding the risk operators' behavior bias towards radiation management.

To provide adequate radiation dose data, due the large individual variability of patient dose in fluoroscopically guided interventional procedures, Vano et al. [22] recommended to collect the radiation data of >50 patients within the same type of procedure for a single center. In this study, the number of cases per type of procedures was >50 for all categories, except for AVF/AVM.

These results could be used as a reference data point for other centers and help in the assessment of their own practice and the technologies used. Indeed, there is an expected increase in neurovascular programs across the world, due to the recently updated guidelines for the early management of patients with acute ischemic stroke regarding endovascular treatment [23].

Our data showed great variability of dose levels between categories (up to a 3.5-fold difference in the median between the subgroup "other interventions" and "AVF/AVM embolization"), mainly due to the difference in procedure complexity and operator experience.

For cerebral angiography, when comparing the radiation dose with that in the available literature, the DAP median value was found to be significantly lower than the published reference value ($p < 0.05$) (Table 1). Third-quartile DAP and FT were also lower compared to those in the literature. The median FT was found to be significantly lower in 6 out of the 7 references tested for statistical differences. The median number of DSA frames was comparable or lower. Mean CAK was found to be significantly lower in comparison with Chung et al. [24] and Schneider et al. [19].

In the intervention group (Table 1), with all procedures combined, the median DAP was significantly lower than the values reported in literature. FT and number of DSA frames were found to be lower, except in comparison with Sarycheva et al. [25] and Söderman et al. [26]. Sarycheva et al. [25] reported a statistically lower mean of FT and number of frames, using 4 monoplane systems (3 equipped with image intensifiers and 1 with a flat-panel detector), but did not provide any precision on the type of therapeutic procedures. The median FT was significantly higher when compared with Söderman et al. [26], which could be explained by a different procedural mix or a larger use of fluoroscopy and stored fluoroscopy in lieu of DSA.

With smaller sample sizes than in other reports of radiation levels, in the subgroups AVF/AVM embolization and aneurysm embolization, the median DAP was significantly lower ($p < 0.01$), except for AVM in Alexander et al. [27], for which there was no statistical difference.

As shown in Table 1, the radiation data (DAP and CAK when applicable) from this study were significantly lower than in most of the published literature since 2003, even when compared with modern equipment. No report of dose levels was found in the literature for comparison with our stroke mechanical thrombectomy dose values.

Potential contributors to lower radiation dose, such as low fluoroscopy framerate, use of variable framerate for DSA, digital zoom on a large display monitor, fluorostore, and advanced imaging capabilities could not be investigated due to the retrospective design of the study. Pearl et al. [18] recently made propositions to implement further dose reduction strategies: some of them were already routinely applied at our center as described in the Materials and Methods section, but others, such as the real-time monitoring of radiation parameters with thresholds to better control radiation level during each procedure or the use of a lower default

DSA framerate (2 vs. 4 fps currently), should also be considered and evaluated with respect to adequate image quality and patient safety.

Optimizing patient radiation is key to reducing scatter radiation and limiting operator dose. However, to further minimize the occupational dose, other protective actions should be considered: personal radiation protection, shielding, operator position, personal dosimeter, and training [28, 29].

This comparison also allowed us to reflect the lack of a standardized method to collect and report radiation exposure for neurointerventional procedures. There is a need to develop national reference levels through a multicentric database with standardized radiation data as well as common neurointerventional nomenclature to compare practices as per radiation safety guidelines.

To our knowledge, this study provides the first radiation data related to stroke mechanical thrombectomy. Using the 75th percentile to our results, as commonly done in other studies, for establishing reference levels, preliminary values for this subgroup are 110 Gy × cm^2 for DAP, 1,020 mGy for CAK, 30 min for FT, and 460 DSA frames. Until broader datasets for stroke mechanical thrombectomy are available, these initial levels could be used by other centers for their own assessment, but should be considered with caution due to the limited sample size and the single-center study design.

Besides the traditional limitation of a single-center retrospective study design, our study has the following additional limitations. In the cerebral diagnostic angiography category, initial diagnostic angiography and follow-up angiographies were not segregated. While initial diagnostic angiography generally refers to the exploration of 4 cerebral vessels or more, follow-up will typically investigate 2 or 3 vessels except in the case of AVF/AVM, which should result in a lower radiation dose.

Per the ALARA principle, there should be a balance between dose and image quality: radiation exposure should not be lowered to a point where the diagnostic level of the images could be jeopardized. In this study, though there was no direct assessment of image quality, the retrospective design suggests that operators focused on procedural success with adequate image quality rather than on achieving low radiation dose alone. The site has been involved in several stroke trials and registries, and their images have to be uploaded and reviewed by national study imaging centers, with no issues having been reported to date. Also, the recanalization rate of mechanical thrombectomy at the site defined as a Thrombolysis in Cerebral Infarction scale score of 2b/3 is 88%. It is on par or exceeds the current published data that led to the change in the guidelines for acute stroke treatment – MR CLEAN [4] (59%), SWIFT PRIME [3] (88%), ESCAPE [30] (72%), EXTEND IA [31] (86%), REVASCAT [32] (66%), and THERAPY [33] (73%). Finally, occupational dosimetry data were not available.

Conclusion

In this study, patient radiation exposure was collected and analyzed for various neurointerventional procedures with varying complexities and found to be in the low range compared to the published literature. According to the ALARA principle, each institution should investigate its own practice regarding radiation exposure and implement dose reduction strategies if required to minimize the dose administered to patients and physicians. In the absence of a safe dose threshold, as technique and equipment continue to evolve, and as the volume and complexity of neurointerventional procedures increase, there would be a need to collect radiation data through local or national surveys to establish reference levels that could help trigger further radiation optimization.

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