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Proposed achievable levels of dose and impact of dose-reduction systems for thrombectomy in acute ischemic stroke: an international, multicentric, retrospective study in 1096 patients

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Abstract

Background International dose reference levels are lacking for mechanical thrombectomy in acute ischemic stroke patients with large vessel occlusions. We studied whether radiation dose-reduction systems (RDS) could effectively reduce exposure and propose achievable levels.

Materials and methods We retrospectively included consecutive patients treated with thrombectomy on a biplane angiography system (BP) in five international, high-volume centers between January 2014 and May 2017. Institutional Review Board approvals were obtained. Technical, procedural, and clinical characteristics were assessed. Efficacy, safety, radiation dose, and contrast load were compared between angiography systems with and without RDS. Multivariate analyses were adjusted according to Bonferroni's correction. Proposed international achievable cutoff levels were set at the 75th percentile.

Results Out of the 1096 thrombectomized patients, 520 (47%) were treated on a BP equipped with RDS. After multivariate analysis, RDS significantly reduced dose–area product (DAP) (91 vs 140 Gy cm^2, relative effect 0.74 (CI 0.66; 0.83), 35% decrease, $p < 0.001$) and air kerma (0.46 vs 0.97 Gy, relative effect 0.63 (CI 0.56; 0.71), 53% decrease, $p < 0.001$) with 75th percentile levels of 148 Gy cm^2 and 0.73 Gy, respectively. There was no difference in contrast load, rates of successful recanalization, complications, or clinical outcome.

Conclusion Radiation dose-reduction systems can reduce DAP and air kerma by a third and a half, respectively, without affecting thrombectomy efficacy or safety. The respective thresholds of 148 Gy cm^2 and 0.73 Gy represent achievable levels that may serve to optimize current and future radiation exposure in the setting of acute ischemic stroke treatment. As technology evolves, we expect these values to decrease.

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Key Points

- *Internationally validated achievable levels may help caregivers and health authorities better assess and reduce radiation exposure of both ischemic stroke patients and treating staff during thrombectomy procedures.*
- *Radiation dose-reduction systems can reduce DAP and air kerma by a third and a half, respectively, without affecting thrombectomy efficacy or safety in the setting of acute ischemic stroke due to large vessel occlusion.*

Keywords Stroke · Thrombectomy · Patient safety

Abbreviations

AIS	Acute ischemic stroke
BP	Biplane angiosuite without radiation dose-reduction system
DAP	Dose–area product
MCA	Middle cerebral artery
mRS	Modified Rankin Scale
MT	Mechanical thrombectomy
mTICI	Modified Thrombolysis In Cerebral Infarction
NIHSS	National Institute of Health Stroke Scale
RDS	Radiation dose-reduction system

Introduction

Thrombectomy has become standard-of-care for acute ischemic stroke (AIS) patients presenting with large vessel occlusions [1–4]. Even late-onset patients benefit from thrombectomy in cases of favorable clinical-imaging mismatch [5–7]. As the number of thrombectomies performed each year continues to grow [8, 9], as well as the increasing proportion of AIS in young patients [10], so too does x-ray exposure, with potentially severe side effects [11, 12]. In order to protect the population beyond the acute phase, it is critical to seek for any method that might reduce thrombectomy patients' X-ray exposure. There are currently no established dose reference levels for a thrombectomy procedure that could help measure and improve the treatment quality of ionizing examinations [13] despite recent publications [14, 15] as already established for many image-guided diagnostic and interventional procedures [16–18].

Since modern biplane angiography systems and flat panel radiation dose-reduction system (RDS) can reduce radiation exposure [19–21], we hypothesized that RDS would reduce radiation exposure, without decreasing efficacy or safety of mechanical thrombectomy (MT). For that purpose, we aimed to:

1) Evaluate if RDS in biplane angiosuites had an influence on the efficacy, safety, radiation exposure, contrast load, and procedure duration of thrombectomy, and
2) Propose internationally validated achievable dose levels to optimize institutional quality control.

Materials and methods

The study protocol was approved by the institutional review boards of the five participating centers in France, Switzerland, the USA, and Canada (see Supplemental material), which complied with the Health Insurance Portability and Accountability Act. Based on previous fruitful scientific collaborations, five academic centers with high-volume interventional activity (> 80 thrombectomies/year) and a prospectively acquired database decided to pool their resources in order to obtain a sufficiently powered trial. No site was excluded. Thrombectomies were performed on biplane systems as often as possible. Single-plane systems were used whenever the biplane suite(s) were not available due to another running procedure or whenever they were under maintenance (physicist performance evaluation and service engineer visit). Patient informed consent was waived by the different review boards for this retrospective study of pooled anonymized data acquired prospectively. Adherence to the STROBE criteria [22] was enforced. No industry support was received for this study. The authors had full control of the data and information submitted for publication, and none are employees or consultants for the industry.

Population

We identified all consecutive thrombectomy procedures performed in the anterior and posterior circulation (first portion of the middle cerebral artery (MCA), second portion of the MCA, internal carotid artery termination, tandem (cervical internal carotid artery plus internal carotid artery termination or first or second portion of the MCA), basilar artery) in five academic centers within four countries using a biplane angiosuite with or without RDS between January 2014 and May 2017. Centers with biplane and single-plane angiosuite typically performed thrombectomies on the latter when the former was not available, for the reasons mentioned above. MT performed on single-plane angiosuites were not included. All patients presented with AIS and large vessel occlusions confirmed by magnetic resonance and/or computed tomography imaging and were initially evaluated by a stroke neurologist and a neuroradiologist. Patients were transferred to the angiosuite only if a thrombectomy could be performed according to international recommendations [23, 24].

Outcome, as defined by modified Rankin Scale [25] (mRS), was assessed at 3 months by certified stroke neurologists. Initial clinical data, including weight, which might influence dose–area product (DAP) for specific procedures [26] and diagnostic imaging data, as well as procedural and post-thrombectomy clinical and imaging data were reviewed (see Supplemental material). All fluoroscopies and serial acquisitions were included in the analysis.

Variables studied were air kerma (Gy), DAP (Gy.cm^2), fluoroscopy duration (min), contrast load (mL), procedure duration (min), modified Thrombolysis In Cerebral Infarction [27] (mTICI) score, mRS at 3 months, and peri-procedural complications.

During the 3-year study period, experienced Interventional Neuroradiology physicians or advanced fellows-in-training with at least 2 years of neurointerventional training performed the fluoroscopy, catheterization, and thrombectomy steps as primary operators, except for center E where fellow involvement consisted essentially of assistance only (see Supplemental material, Table A2). Patients subjected to thrombectomy within 15 days following the implementation of the RDS were excluded from the analysis to limit variation bias related to software adjustment and fine tuning of image quality, as occurred in centers A and B, which upgraded their angiosuites during the inclusion period (see Supplemental material, Table A1).

Dose metrics

DAP is a surrogate measure of the amount of energy delivered to patients [17] while air kerma is the dose accumulated at the patient entrance reference point [17]. Since these parameters vary from one practice to another, specifications and technical parameters of each angiosuite were obtained from the radiophysic department of all participating centers (see Supplemental material, Tables A1 and A2) and reviewed by two radio-physicists (S.M. and F.C.). All dose reports were extracted from the different picture archiving systems by a local interventional neuroradiologist and/or physicist in each center. Calibration of the DAP was regularly performed by the two main angiosuite vendors involved (Philips or Siemens) and measurements obtained according to international standards. A 27- or 32-cm field of view was used for the vast majority and during most of the procedures. Furthermore, we did not measure the exact percentage of cases where collimation was applied, although it was a systematic and usual approach in all centers for fluoroscopy and angiographic runs in order to limit exposure.

Statistics/data analysis

A descriptive analysis of the data was performed. Categorical variables were summarized using frequency, pure and cumulative percentages. Continuous variables were treated using mean, standard deviation, quartile, and inter-quartile ranges. The normality of the continuous variables was tested using the Shapiro–Wilk tests. The eight variables of interest (air kerma (Gy), DAP (Gy cm^2), fluoroscopy duration (min), contrast load (mL), procedure duration (min), mTICI score, mRS at 3 months, and peri-procedural complications) were compared using the Mann–Whitney U test for continuous variables and the Fisher test for categorical variables. Eight different models were further used to identify potential confounders. Due to the skewed distribution of all continuous variables, a simple linear regression could not be used. For continuous variables, a linear regression with log-transformed variables was used if histograms and residual plots did not show any deviation from normality. For binary variables, a logistic regression was used. Multiple regression was then performed to adjust for different confounders, including age, gender, occlusion level and side, center, date of the procedure, type of anesthesia, number of diagnostic angiograms, thrombectomy technique (stent retriever, direct aspiration, or combined), prior administration of intra-venous thrombolysis, and angiography equipment manufacturer used to perform the thrombectomy (Philips or Siemens). Bonferroni's correction was used to avoid inflation of type I error related to the use of eight independent tests. All statistical analyses were performed using the "R" Statistical Software (version 3.4.2). P value < 0.05 was set for significance.

We assumed radiation dose did not have to be adjusted or corrected according to patient weight since weight distribution was similar between groups and because thrombectomy is focused on the head and neck region [26].

We selected the third quartile or 75th percentile [13, 28] of the radiation dose as the threshold for achievable levels, as previously recommended [29–32].

Results

Between January 2014 and May 2017, 1426 thrombectomies were performed. After excluding procedures performed on single-plane units (302 interventions, which will be the focus of a separate study) or with incomplete dose reports (28 procedures due to faulty automatic transmission, file corruption, or premature shutdown of the machine during transfer to the PACS), 1096 patients remained for analysis. RDS was used in 520 cases. There was no major difference in baseline characteristics between patients treated with or without RDS.

Mean age, weight, and NIHSS were, respectively, 70 years (range 18–101; median [IQR] = 72 [59–82]), 77 kg (range 38–142; median [IQR] = 75 [65–86]), and 17 points (range 0–33; median [IQR] = 17 [12–21]). There were 556 (51%) women. Patient's distribution between centers was significantly different ($p < 0.05$) between groups, as well as dates of MT, type of anesthesia, realization of a diagnostic angiogram, and

technique of the MT. Symptom onset to groin puncture delay did not differ significantly between groups. The relative percentage of patients with dissection versus cardiac or non-cardiac embolic origin was not significantly different between both groups (for complete information, please report to Table 1).

Table 1 Baseline demographics of patients treated with and without RDS biplane systems

Biplane angiosuite type	All, *n* (%)	With RDS, *n* (%)	Without RDS, *n* (%)
Patients (*n*)	1096 (100)	520 (47.5)	576 (52.5)
Center			
A	359/1096 (33)	271/520 (52.1)	88/576 (15.3)*
B	454/1096 (41)	145/520 (27.9)	309/576 (53.6)
C	151/1096 (14)	0/520 (0)	151/576 (26.2)
D	104/1096 (9)	104/520 (20)	0/576 (0)
E	28/1096 (3)	0/520 (0)	28/576 (4.9)
Dates			
Before 2015	106/1096 (10)	18/520 (3)	88/576 (15)*
2015	439/1096 (40)	134/520 (26)	305/576 (53)
After 2015	551/1096 (50)	368/520 (71)	183/576 (32)
Gender			
Male	544/1096 (49.5)	257/520 (49.4)	287/576 (49.8)
Female	552/1096 (50.5)	263/520 (50.6)	289/576 (50.2)
Age (years): median, Q1, Q3	72 (59–82)	72 (60–81)	72 (59–82)
Weight (kg): median, Q1, Q3	75 (65–86)	76 (66–86)	75 (65–86)
Pre-stroke mRS: median, Q1, Q3	0 (0–1)	0 (0–0)	0 (0–1)
Onset NIHSS: median, Q1, Q3	17 (12–21)	18 (12–21)	17 (12–21)
Onset to groin: median, Q1, Q3	249 (231–279)	255 (235–285)	244 (230–273)
Supra-aortic imaging			
Yes	777/1096 (71)	413/520 (79)	364/576 (63)
No	319/1096 (29)	107/520 (21)	212/576 (37)
Side			
Right	461/1096 (42)	217/520 (42)	244/576 (42)
Left	540/1096 (49)	249/520 (48)	291/576 (51)
Midline (basilar artery)	95/1096 (9)	54/520 (10)	41/576 (7)
Level of occlusion			
MCA-M1	541/1096 (49)	238/520 (46)	303/576 (53)
MCA-M2	149/1096 (14)	70/520 (14)	79/576 (14)
Terminal ICA	178/1096 (16)	81/520 (16)	97/576 (17)
Tandem	132/1096 (12)	76/520 (14)	56/576 (9)
Basilar artery	96/1096 (9)	55/520 (10)	41/576 (7)
Intravenous thrombolysis			
Yes	715/1096 (65)	333/520 (64)	382/576 (66)
No	381/1096 (35)	187/520 (36)	194/576 (34)
Anesthesia			
General (GA)	457/1096 (42)	281/520 (54)	176/576 (30) *
Conscious sedation (CS)	618/1096 (56)	234/520 (45)	384/576 (67)
CS converted in GA	21/1096 (2)	5/520 (1)	16/576 (3)
Diagnostic angiogram ≥ 3 vessels			
Yes	381/1096 (35)	51/520 (10)	330/576 (57) *
No	715/1096 (65)	469/520 (90)	246/576 (47)
Technique			
Stent retriever	501/1096 (46)	315/520 (61)	186/576 (32) *
Aspiration	363/1096 (33)	135/520 (26)	228/576 (40)
Combined	232/1096 (21)	70/520 (13)	162/576 (28)
Stenting and/or angioplasty			
Yes	128/1096 (12)	51/520 (10)	77/576 (13)
No	968/1096 (88)	469/520 (90)	499/576 (87)
Stroke etiology			
Cardioembolic	601/1096 (56)	284/520 (55)	317/576 (58)
Atherosclerosis	209/1096 (20)	122/520 (23)	87/576 (16)
Dissection	50/1096 (5)	25/520 (5)	25/576 (4)
Other	208/1096 (19)	89/520 (17)	119/576 (22)

RDS, radiation dose-reduction system; *n*, number; *Q1–Q3*, first and third quartile; *mRS*, modified Rankin Scale; *NIHSS*, National Institute of Health Stroke Scale; *MCA-M1*, first portion of the middle cerebral artery; *MCA-M2*, second portion of the middle cerebral artery; *Terminal ICA*, internal carotid artery termination; *GA*, general anesthesia

*Significant difference between groups, $p < 0.05$, used as confounding variables in multivariate regression

Technical and clinical outcomes

Multivariate analysis (Table 2) showed a significant dose reduction in patients treated with RDS with a mean DAP of 91 Gy cm^2 (vs 140 Gy cm^2 without RDS, relative effect 0.74 [CI 0.66; 0.83], 35% decrease, $p < 0.001$) and a mean air kerma of 0.46 Gy (compared to 0.97 Gy without RDS, relative effect 0.63 [CI 0.56; 0.71], 53% decrease, $p < 0.001$).

Successful recanalization rate (mTICI 2b/3), complication rate (ischemic or hemorrhagic events), good clinical outcome rate (mRS 0–2), fluoroscopy duration (min), contrast load (mL), and procedure duration (min) did not differ in patients treated with or without RDS after multivariate analysis (Table 2).

Achievable levels

Proposed achievable levels for DAP (Gy.cm^2), air kerma (Gy), and contrast load (mL) during intracranial thrombectomy performed on biplane systems equipped with or without RDS are summarized in Tables 3 and 4. The 10th, 25th, 50th, 75th, and 95th percentiles of DAP and air kerma are compared between both angiography systems in Figs. 1 and 2.

For patients treated on a biplane system with RDS, the 75th percentiles for DAP, air kerma, and contrast load were 148 Gy cm^2, 0.73 Gy and 172 mL, respectively. For occlusions of the first portion of the middle cerebral artery treated on a biplane RDS system ($n = 238$), the 75th percentiles for DAP, air kerma, and contrast load were 114 Gy.cm^2, 0.59 Gy, and 140 mL, respectively.

Discussion

Overall, use of RDS in thrombectomy resulted in a 35% decrease in DAP and 53% in air kerma. RDS did not affect the rate of successful recanalization, complication, or good clinical outcome at 3 months. Using the 75th percentile of DAP and air kerma in our cohort of thrombectomy patients treated on a biplane RDS system, we obtained achievable levels of 148 Gy cm^2 and 0.73 Gy, respectively, which may serve to optimize current and future radiation exposure in the setting of endovascular acute ischemic stroke treatment. Fluoroscopy duration was lower in biplane RDS in univariate analyses but not anymore after adjustments, despite no difference in image quality reported in the literature. However, there was no difference in procedure duration.

Despite the risk of cardiovascular [33] or oncologic death [34] due to radiation exposure among atomic bomb survivors and reports mentioning confounding factors such as smoking in oncologic death among Chernobyl emergency workers, the linear dose–response relationship for the induction of cancer and heritable effects implies that any exposure increment induces a proportional risk increment for long-term adverse events, even at low doses. Moreover, despite the lack of statistical validation, controversial case reports of left-sided brain tumors in the interventional cardiology community have emerged [35]. Consequently, any treating physician working in an ionizing environment should try to reduce exposure at all costs, such upgrading to RDS angiographic systems.

Studies reporting median and mean DAP of neuroendovascular treatments are scarce. Soderman et al [20] described a median DAP of 328 Gy.cm^2 before and 109 Gy.cm^2 after implementation of RDS (67% decrease) for multiple endovascular treatments but did not provide specific numbers for thrombectomy alone. Our data supports the radioprotective benefits of RDS reported in earlier preliminary neurovascular and other interventional studies [19, 20]. Importantly, our data shows that RDS does not negatively affect the safety and effectiveness of intra-cranial thrombectomy.

Table 2 Comparison between biplane imaging with and without RDS

Angiosuite type	Biplane RDS, *n* (%)	Biplane, *n* (%)	*p* value univariate	*p* value multivariate
Patients (1096 total)	520/1096 (47.5)	576/1096 (52.5)		
Recanalization rate (TICI 2b-3)	425/520 (81.7)	480/576 (83.3)	0.14	NS
Complication rate	69/520 (13.3)	89/576 (15.5)	0.89	NS
Procedure duration (min): median, Q1, Q3	56 (35–85)	44 (30–73)	0.0001	NS
24 h NIHSS: median, Q1, Q3	11 (5–20)	12 (4–20)	0.67	NS
3 months good mRS (0-1-2)	247/520 (47.5)	231/576 (40.1)	0.83	NS
DAP (Gy cm^2): median, Q1, Q3	91 (57–148)	140 (92–235)	0.0001	0.001*
Air kerma (Gy): median, Q1, Q3	0.46 (0.3–0.7)	0.97 (0.6–1.7)	0.0001	0.001*
Contrast load (mL): median, Q1, Q3	116 (75–173)	100 (60–180)	0.06	NS
Fluoroscopy duration (min): median, Q1, Q3	18 (11–28)	22 (14–37)	0.001	NS

NS, not significant; *RDS*, radiation dose-reduction system; *n*, number; *Q1–Q3*, first and third quartile; *NIHSS*, National Institute of Health Stroke Scale; *mRS*, modified Rankin Scale; *DAP*, dose–area product

*Remained significant

Table 3 Proposed achievable levels for mechanical thrombectomy on BP-RDS

Variable	Occlusion	*n*	Min	25th percentile	Median	Mean	75th percentile	Max
DAP (Gy.cm^2)	M1	238	18	53	76	91	114	342
	M2	70	17	53	87	103	129	401
	ICA T	81	11	64	99	118	148	383
	Tandem	76	33	118	166	180	203	697
	Basilar	55	18	57	96	134	197	324
	All	520	11	57	91	114	148	697
Air kerma (Gy)	M1	238	0.06	0.28	0.37	0.47	0.59	2.13
	M2	70	0.10	0.27	0.44	0.56	0.63	2.55
	ICA T	81	0.12	0.33	0.49	0.62	0.78	2.00
	Tandem	76	0.22	0.51	0.77	0.98	1.06	5.65
	Basilar	55	0.12	0.31	0.50	0.77	1.08	2.25
	All	520	0.06	0.30	0.46	0.61	0.73	5.65
Contrast (mL)	M1	238	16	60	100	110	140	320
	M2	70	25	60	100	109	140	350
	ICA T	81	15	80	130	136	175	350
	Tandem	76	60	137	174	185	230	350
	Basilar	55	20	80	130	157	200	426
	All	520	15	75	116	130	172	426

BP-RDS, biplane with radiation dose-reduction system; *n*, number; *Max*, maximum; *Min*, minimum; *DAP*, dose–area product

There are currently no international reference levels available for cerebral thrombectomy, despite single-center recent descriptions of dose levels in stroke interventions. Such levels in interventional radiology are not derived from standardized examinations on phantoms [36] because of important inter-individual variability [37]. Using a multicentric cohort of thrombectomy procedures performed by operators unaware of the study purpose and thus not influenced by their drive

Table 4 Distribution of DAP, air kerma, and contrast load for mechanical thrombectomy performed on BP and BP-RDS

Variable	Occlusion	*n*	Min	25th percentile	Median	Mean	75th percentile	Max
DAP (Gy.cm^2)	M1	541	10	65	99	125	153	665
	M2	149	16	74	103	132	149	826
	ICA	178	11	76	134	171	216	1382
	Tandem	132	33	137	197	219	268	1697
	Basilar	96	18	68	135	180	264	1745
	All	1096	10	74	116	149	187	1745
Air kerma (Gy)	M1	541	0.06	0.35	0.58	0.82	1.08	6.50
	M2	149	0.10	0.39	0.60	0.92	1.09	6.22
	ICA	178	0.12	0.44	0.76	1.09	1.43	4.88
	Tandem	132	0.22	0.67	1.02	1.30	1.62	5.65
	Basilar	96	0.10	0.38	0.67	1.20	1.75	10.49
	All	1096	0.06	0.40	0.66	0.97	1.21	10.49
Contrast (mL)	M1	541	10	60	100	117	150	500
	M2	149	20	60	100	103	140	400
	ICA	178	15	80	113	140	190	400
	Tandem	132	40	135	168	186	250	420
	Basilar	96	20	70	100	144	190	500
	All	1096	10	70	105	129	180	500

DAP, dose–area product; *BP*, biplane angiosuite without dose reduction system; *BP-RDS*, biplane with radiation dose-reduction system; *n*, number; *Max*, maximum; *Min*, minimum

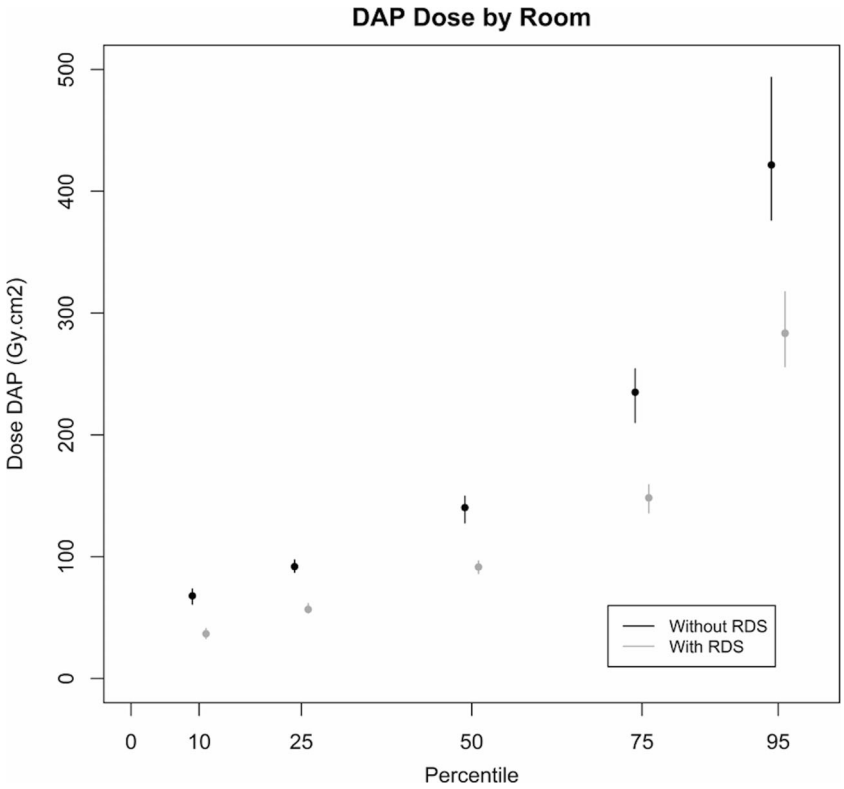

Fig. 1 Comparison of DAP percentiles (with confidence intervals [CI]) on biplanes with and without RDS. This figure provides the comparison of DAP between both types of angiosuites. Doses for the angiosuites without RDS are depicted in dark, and doses for the angiosuites with RDS are indicated in light gray. RDS resulted in significantly lower DAP doses for each percentile. Achievable cutoff levels were set at the 75th percentile and shows a significant difference. DAP, dose–area product; RDS, radiation dose-reduction system

to reduce radiation dose [16], we propose achievable levels, which could serve as quality-control thresholds for certification or accreditation purposes [13]. Indeed, these achievable exposure levels may help to improve radioprotective measures (physician doses were not recorded in this study) in accordance with the as low as reasonably

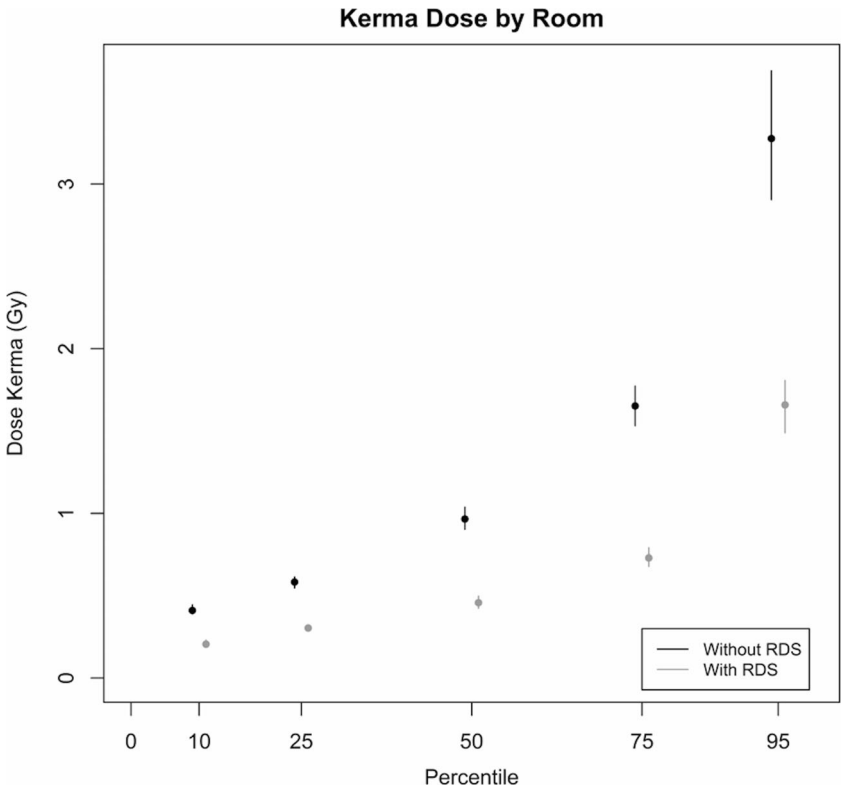

Fig. 2 Comparison of air kerma percentiles (with confidence intervals [CI]) on biplanes with and without RDS. This figure provides the comparison of air kerma between both types of angiosuites. Doses for the angiosuites without RDS are indicated in dark, and doses for the angiosuites with RDS are indicated in light gray. RDS resulted in significantly lower air kerma doses for each percentile. Achievable cutoff levels were set at the 75th percentile and shows a significant difference. RDS, radiation dose-reduction system

achievable (ALARA) and as high as reasonably achievable (AHARA) principles [16, 38, 39], especially knowing that radiation exposure is cumulative [40–42] with pre-therapeutic diagnostic exams, such as CT angiography and perfusion, that are used to triage patients [43] towards endovascular treatment.

Limitations

Aside from the retrospective nature of this study and inherent bias, our RDS data reflects largely the "Philips AlluraClarity" reduction dose system from Philips (Philips Healthcare) which includes a series of new software options not available on the other angiosuites described. Systems identified as non-RDS in this study have other but different and older radiation dose-reduction features installed.

Since the latest upgrades were not necessarily installed in every center, it remains unclear whether one vendor offers better dose-reduction systems than the competitors, hence the importance of defining and regularly updating achievable levels for thrombectomy. Furthermore, data were collected from high-volume academic centers, which may not necessarily be reflective of other settings [16]. Another potential limitation was the exclusion of cone-beam computed tomography, which was, however, rarely performed. Although this represents only a small fraction of the cumulative air kerma [19, 20, 44], the additional dose related to cone-beam computed tomography exposure should be properly addressed in future studies. Conversely, contrast-enhanced cone-beam computed tomography through an IV or a pigtail aortic arch injection might eliminate the need for non-productive selective angiography in selected patients and hence perhaps reduce exposure overall. All angiosuites did not include the same digital-subtraction angiography frame rates and could affect results.

In the group without RDS, a diagnostic angiogram of three supra-aortic vessels or more was obtained in half of the patients to evaluate collateral flow before thrombectomy, compared to a tenth in the RDS group, although these few additional digital-subtraction angiography turned out to be non-significant after multivariate analysis. The disparity in strategy and in the number of diagnostic angiograms (exact number of digital-subtraction angiography runs unavailable) between the RDS and non-RDS populations can be explained by the fact that by time RDS was implemented, most centers relied more on other advanced diagnostic tools to evaluate collateral flow, such as perfusion imaging or multiphase computed tomography angiogram [45].

Although subgroup analyses were attempted for patients with tandem and terminal internal carotid artery occlusions, showing a trend towards higher DAP, air kerma, and contrast load, the groups were insufficiently powered to establish achievable levels according to occlusion site. We faced the same issue concerning subgroups based on etiology, which were similar between groups. Indeed, Marshall et al [46] showed that radiation dose data from at least 100 patient examinations, performed in several fluoroscopy units, are required to produce valid and reproducible reference levels. Additionally, thrombectomies are often performed on single-plane angiosuites worldwide, but it remains uncertain if the achievable levels we propose on biplane systems are identical. Further dedicated studies are needed to address this issue. Finally, the achievable levels (75th percentile) we suggest are not intended for individual dose comparisons and need to be confirmed by further and larger trials.

Conclusion

Radiation dose-reduction system can reduce DAP and air kerma exposure by a third or a half, respectively, without affecting the efficacy and safety of intra-cranial thrombectomy. The achievable levels we propose for DAP and air kerma in neurothrombectomy procedures are 148 Gy cm^2 and 0.73 Gy, respectively, which may serve as quality-control thresholds. As technology and operator experience evolve, we expect these levels to further diminish.

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