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Clinical Article

Reducing frame rate and pulse rate for routine diagnostic cerebral angiography: ALARA principles in practice

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Objective: Diagnostic cerebral angiograms (DCAs) are widely used in neurosurgery due to their high sensitivity and specificity to diagnose and characterize pathology using ionizing radiation. Eliminating unnecessary radiation is critical to reduce risk to patients, providers, and health care staff. We investigated if reducing pulse and frame rates during routine DCAs would decrease radiation burden without compromising image quality.

Methods: We performed a retrospective review of prospectively acquired data after implementing a quality improvement protocol in which pulse rate and frame rate were reduced from 15 p/s to 7.5 p/s and 7.5 f/s to 4.0 f/s respectively. Radiation doses and exposures were calculated. Two endovascular neurosurgeons reviewed randomly selected angiograms of both doses and blindly assessed their quality.

Results: A total of 40 consecutive angiograms were retrospectively analyzed, 20 prior to the protocol change and 20 after. After the intervention, radiation dose, radiation per run, total exposure, and exposure per run were all significantly decreased even after adjustment for BMI (all $p<0.05$). On multivariable analysis, we identified a 46% decrease in total radiation dose and 39% decrease in exposure without compromising image quality or procedure time.

Conclusions: We demonstrated that for routine DCAs, pulse rate of 7.5 with a frame rate of 4.0 is sufficient to obtain diagnostic information without compromising image quality or elongating procedure time. In the interest of patient, provider, and health care staff safety, we strongly encourage all interventionalists to be cognizant of radiation usage to avoid unnecessary radiation exposure and consequential health risks.

Keywords Cerebral angiography, Radiation, Fluoroscopy, Endovascular procedures, ALARA

INTRODUCTION

As the demand for neuroendovascular procedures increases, applying the principles of "As Low As Reasonably Achievable" (ALARA) is critical to mitigate ionizing radiation dose to patients and providers.[1] The stochastic and deterministic effects of radiation are known to cause cancer, reduce lifespan, cause harmful epigenetic mutations and cause cataracts.[5)8)12)] A routine six vessel diagnostic cerebral angiogram (DCA) in biplane can have the equivalent radiation dose measured in milligray (mGy) of 10 non contrast CT scans of the head. The potential for harm also extends to both the operator and operating staff present in the facility.[2] A variety of attempts have been made to discover a permutation of settings that lessen radiation exposure but seemingly lack a robust method of assessing integrity of image quality and consideration of changing body habitus of patients.[3)4)7)15)16)] We conducted an internal quality review at our institution to understand the default pulse and frame rate and determine if reducing these values could decrease radiation dose to the patient and exposure while maintaining sufficient quality in diagnostic views as verified by two blinded endovascular neurosurgeons.

MATERIALS AND METHODS

We performed a retrospective review of prospectively acquired data on a Siemens Artis Q biplane after implementing a quality improvement protocol in January 2022 in which pulse rate and frame rate in our biplane suit were reduced from 15 p/s to 7.5 p/s and 7.5 f/s to 4.0 f/s respectively. All procedures were performed on the same biplane. Total radiation dose, radiation per angiographic run, total radiation exposure, and exposure per run were calculated. Subsequently, two blinded endovascular neurosurgeons reviewed all included angiograms of both the higher and lower dose to determine if any angiograms provided insufficient information for diagnosis based on image quality. The angiograms reviewed covered a variety of neurosurgical pathologies detected by diagnostic angiograms and respective percent compositions within the study were calculated and reported in Table 1. Radiation dose is reported as mGy and radiation exposure is reported as μGym^2. Counts and proportions are reported for count variables. Descriptive statistics of continuous and categorical variables were performed using independent samples t-tests and Chi squared tests, respectively. Multivariable log-linear regression was performed to account for patient body mass index (BMI), number of angiographic runs, and number of vessels catheterized. Statistical analysis was performed using STATA MP Version 14.1 (Stata Corp LP, College Station, Texas, USA). All tests were two-sided. Significance was defined as $p<0.05$.

RESULTS

A total of 40 consecutive angiograms were retrospectively analyzed, 10 prior to the protocol change and 10 after (Table 2). Univariable analysis revealed that radiation dose (554.0 vs. 383.6 mGy, $p=0.003$), radiation dose per angiographic run (33.0 vs. 21.8 mGy/run, $p<0.001$), total radiation exposure (7043.4 vs. 5081.9 mGym^2, $p=0.016$), and exposure per run (408.8 vs. 291.9, $p<0.001$) were all significantly decreased after the protocol was implemented. BMI was higher after protocol implementation (23.8 vs. 28.8 kg/m^2, $p=0.024$).

Table 1. Categories of pathology of diagnostic angiograms included in the study and percent composition

Pathology	Count	Percentage
Moyamoya	3	7.5
Bow Hunter's Syndrome	1	2.5
Artery stenosis	6	15
AVM	11	27.5
AVF	1	2.5
Aneurysm	11	27.5
Vasculitis	2	5
Dissection	1	2.5
Stent occlusion	2	5
RCVS	2	5

Table 2. Data for angiography runs before and after pulse and frame rate reductions is detailed here

Factor	Before	After	p-value
N	20	20	
BMI, mean (SD)	23.8 (3.9)	28.8 (8.8)	0.024
Total mGy, mean (SD)	554.0 (201.3)	383.6 (129.0)	0.003
Total Exposure, mean (SD)	7043.4 (2982.7)	5081.9 (1766.0)	0.016
Fluoroscopy time (minutes), mean (SD)	9.3 (5.7)	10.3 (4.3)	0.54
Total mGy per minute of fluoroscopy time, mean (SD)	72.3 (31.4)	41.7 (15.8)	<0.001
Vessels catheterized, mean (SD)	4.8 (1.7)	4.8 (1.7)	1.00
Total mGy per vessel catheterized, mean (SD)	126.3 (41.9)	105.8 (99.2)	0.40
Total exposure per run, mean (SD)	408.8 (93.9)	291.9 (96.6)	<0.001
N of runs, mean (SD)	17.4 (7.1)	18.2 (5.5)	0.66
Total mGy per run, mean (SD)	33.0 (6.4)	21.8 (6.6)	<0.001

SD, standard deviation; mGy, milligray

Average patient fluoroscopy time, number of vessels catheterized, and number of angiographic runs did not differ between groups, demonstrating no change in procedural time or practice despite the change in protocol.

On multivariable log-linear regression adjusting for BMI, number of runs, vessels catheterized, and fluoroscopy time, the ALARA protocol was associated with a 46.1% decrease in the total radiation dose (95% Confidence Interval [CI] 30.6-61.6%, p<0.001) and a 50.9% decrease in radiation dose per run (36.4-65.3%, p<0.001). Total radiation dose was increased 1.4% per unit of BMI (0.2-2.5%, p=0.019), 2.0% per minute of fluoroscopy time (0.3-3.7%, p=0.019), and 2.7% per run (1.3-4.2%, p<0.001).

The protocol was associated with a 39.4% decrease in the total radiation exposure (22.2-56.6%), p<0.001) and a 43.1% decrease in exposure per run (27.3-59.0%, p<0.001). There was an increase in total exposure by 1.4% per unit of BMI (0.2-2.7%, p=0.028), 2.7% per minute of fluoroscopy time (0.8-4.5%, p=0.006), and 2.5% per run (1.0-4.1%, p=0.002) No changes in image quality were identified by two expert endovascular neurosurgeons.

DISCUSSION

The advent of digital subtraction angiography (DSA) has enhanced the diagnosis and treatment of numerous cerebrovascular pathologies. Due to its superior sensitivity, cerebral angiography is generally the preferred diagnostic method for subtle subarachnoid hemorrhages without an obvious aneurysm, surveillance of carotid artery stenosis, vasculitis workup, and assessment of cerebral vasospasm. Despite advances in MR and CT angiography, there are several settings in which DSA is more sensitive and reliable (e.g. intracranial aneurysms less than 3 mm).[17)] The rise of neuroendovascular imaging and interventions in the past few decades has been immensely beneficial; while rare, it does pose risk of ischemic strokes, cerebral vasospasm, access-site hematomas, contrast allergy, and increased radiation dose.[10)]

While efforts to understand and avoid these complications have been explored, the discussion around minimizing radiation exposure without compromising diagnostic yield in neurologic patients remains open. At our institution, we retrospectively reviewed radiation dose and exposure after implementing a dose reduction strategy in Jan 2022 wherein we reduced the pulse rate from 15 p/s to 7.5 p/s and frame rate from 7.5 f/s to 4.0 f/s.

Our analysis of consecutive angiograms before and after the aforementioned dose reduction strategy demonstrated a reduction in radiation per run by 50.9% and exposure per run by 43.1%. This represents a substantial decrease in radiation while not increasing procedural time or lowering diagnostic yield. The reduction seen is also corroborated by Pearl et al.'s dose reduction studies on adult skull and abdomen/pelvis anthropomorphic phantoms.[7] Their study assessed the effect of separate dosing strategies for femoral artery access, roadmap guidance, and cerebral DSA. During roadmap guidance the models received significantly lower radiation exposure at pulse rates of 3 or 4 p/s when compared to 7.5-15 p/s.

The results from our study represent the first retrospective review of prospectively collected data of radiation exposure by reducing pulse and frame rates.[14] Pearl et al.'s proposed radiation reduction strategies were adopted by Schneider et al. into a trial of 231 consecutive angiograms that led to overall reduced radiation doses.[7][11] However, while the trial was ongoing, they improved awareness within their institution of limiting radiation exposure resulting in increased documentation of numerous parameters and limiting fluoroscopy times as much as possible. It is not immediately clear if the changes seen were primarily due to the trial intervention or a conscious effort to minimize exposure, regardless the trial proved effective with reduction of radiation exposure.

While the lowest acceptable limit for a DSA frame rate has yet to be determined, we show that reducing frame rate from 7.5 f/s to 4.0 f/s can lead to meaningful decreases in radiation exposure. A study using adult sized head phantoms showed that a 40-42-fold reduction in radiation could be achieved with a VFR of 2 f/s x 4s and 1s thereafter, in comparison to the vendor default of 3 f/s. However in this comparison, the dose setting (μGy/frame) was varied in that the variable frame rate (VFR) treatments received a lower dose setting.[6] Similarly, Schneider et al. utilized VFRs of 2 f/s during arterial phases followed by 1 f/s for the venous phases without compromising image quality.[11] This is admittedly a considerably low frame rate, and the authors did utilize a higher fixed frame rate of 4-6 f/s for high flow lesions such as AVMs or high-flow arteriovenous fistulas.

The use of low VFRs with the selective use of a higher fixed frame rate for cerebral angiograms appears effective and potentially presents an even lower limit to explore. However, it is challenging to standardize and compare results across these studies. We have examined the effect of reducing fixed frame rates in a controlled manner while existing studies have only examined VFRs. The inability to directly compare is further challenged by the fact that unlike our study, prior studies examined the effects of VFR while modifying other parameters simultaneously. Furthermore, the existing data on reducing radiation exposure in cerebral angiography are unclear on how image quality fared with their interventions. We sought to address this in our own trial by involving two endovascular neurosurgeons to evaluate angiograms of both lower and higher dosing strategies in a blinded manner. None of the angiograms were found to be lacking in diagnostic information.

Our data also assesses radiation exposure during cerebral angiograms of patients with obesity-range BMI. Prior work has shown in invasive cardiac imaging that both operator and patient radiation exposure is significantly increased with increasing BMI.[9][13] Our multivariable analysis demonstrates that radiation exposure does significantly increase with higher BMI in endovascular neurosurgery.

Radiation exposure can be reduced in a multitude of ways in addition to modifying pulse and frame rates. We recommend that providers implement ALARA principles and consider being intentional about the default settings that their fluoroscopic machines offer. Through being intentional about settings, interventionalists can select appropriate pulse and frame rates to obtain sufficient diagnostic information without unnecessary radiation. Our work demonstrates that default settings can be safely lowered without compromising diagnostic information or increasing procedural time – a clear opportunity to definitively improve the practice of angiography while reducing radiation for patients, providers, and staff.

CONCLUSIONS

DCA is widely used for the assessment of numerous intracranial pathologies and with its superior spatial resolution and sensitivity comes the risk of radiation exposure. We have shown a 46% decrease in total radiation dose and 39% decrease in exposure by implementing a protocol that decreases the pulse rate and frame rate without compromising image quality. In the interest of patient, provider, and health care staff safety, we strongly encourage all interventionalists to be cognizant of pulse rate and frame rate and adopt lower frame and pulse rates to avoid unnecessary radiation exposure and consequential health risks.

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Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

REFERENCES

1. Kaplan DJ, Patel JN, Liporace FA, Yoon RS. Intraoperative radiation safety in orthopaedics: A review of the ALARA (As low as reasonably achievable) principle. Patient Saf Surg. 2016 Dec;10:27.
2. Kemerink G, Frantzen M, Oei K, Sluzewski M, van Rooij W, Wilmink J, et al. Patient and occupational dose in neurointerventional procedures. Neuroradiology. 2002 Jun;44(6):522-8.
3. Kim DJ, Park MK, Jung DE, Kang JH, Kim BM. Radiation dose reduction without compromise to image quality by alterations of filtration and focal spot size in cerebral angiography. Korean J Radiol. 2017 Jul-Aug;18(4):722-8.
4. Maeng JY, Song Y, Sung YS, Kim TI, Lee DH, Kim TH. Feasibility of ultra-low radiation dose digital subtraction angiography: Preliminary study in a simplified cerebral angiography phantom. Interv Neuroradiol. 2019 Oct;25(5):589-95.
5. Mooney RB, McKinstry CS, Kamel HA. Absorbed dose and deterministic effects to patients from interventional neuroradiology. Br J Radiol. 2000 Jul;73(871):745-51.
6. Morris PP, Geer CP, Singh J, Brinjikji W, Carter RE. Radiation dose reduction during neuroendovascular procedures. J Neurointerv Surg. 2018 May;10(5):481-6.
7. Pearl MS, Torok C, Wang J, Wyse E, Mahesh M, Gailloud P. Practical techniques for reducing radiation exposure during cerebral angiography procedures. J Neurointerv Surg. 2015 Feb;7(2):141-5.
8. Peterson EC, Kanal KM, Dickinson RL, Stewart BK, Kim LJ. Radiation-induced complications in endovascular neurosurgery: Incidence of skin effects and the feasibility of estimating risk of future tumor formation. Neurosurgery. 2013 Apr;72(4):566-72.
9. Refahiyat L, Clarey A, Bundy J, Mandieka E, Benavides D, Crane T, et al. Impact of patient body mass index on nurse radiation dose during coronary angiography. J Am Coll Cardiol. 2018 Mar;71(11_Supplement):A1032-2.
10. Rosenblum JD, Pasternak O, Mitchell MT. Complications of neuroimaging. Handb Clin Neurol. 2014;121:1743-50.
11. Schneider T, Wyse E, Pearl MS. Analysis of radiation doses incurred during diagnostic cerebral angiography after the implementation of dose reduction strategies. J Neurointerv Surg. 2017 Apr;9(4):384-8.
12. Thierry-Chef I, Simon SL, Land CE, Miller DL. Radiation dose to the brain and subsequent risk of developing brain tumors in pediatric patients undergoing interventional neuroradiology procedures. Radiat Res. 2008 Nov;170(5):553-65.
13. Vargas FG, da Silva BS, de Oliveira Cardoso C, Leguisamo N, de Moraes CAR, de Moraes CV, et al. Impact of body weight on radiation exposure during invasive cardiac procedures. Rev Bras Cardiol Invasiva Engl Ed. 2012 Jan;20(1):63-8.
14. Vehmas T. Hawthorne effect: Shortening of fluoroscopy times during radiation measurement studies. Br J Radiol. 1997 Oct;70(838):1053-5.
15. Yanch JC, Behrman RH, Hendricks MJ, McCall JH. Increased radiation dose to overweight and obese patients from radiographic examinations. Radiology. 2009 Jul;252(1):128-39.
16. Yi HJ, Sung JH, Lee DH, Kim SW, Lee SW. Analysis of radiation doses and dose reduction strategies during cerebral digital subtraction angiography. World Neurosurg. 2017 Apr;100:216-23.
17. Yoon NK, McNally S, Taussky P, Park MS. Imaging of cerebral aneurysms: A clinical perspective. Neurovascular Imaging. 2016 Dec;2(1):6.