



Clinical Article

# ALARA principles in practice: reduced frame and pulse rates for middle meningeal artery embolization

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**Objective:** As the prevalence of neuroendovascular interventions increases, it is critical to mitigate unnecessary radiation for patients, providers, and health care staff. Our group previously demonstrated reduced radiation dose and exposure during diagnostic angiography by reducing the default pulse and frame rates. We applied the same technique for basic neuroendovascular interventions.

**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. We studied consecutive, unilateral middle meningeal artery embolizations treated with particles. Total radiation dose, radiation per angiographic run, total radiation exposure, and exposure per run were calculated. Multivariable log-linear regression was performed to account for patient body mass index (BMI), number of angiographic runs, and number of vessels catheterized.

**Results:** A total of 20 consecutive, unilateral middle meningeal artery embolizations were retrospectively analyzed. The radiation reduction protocol was associated with a 39.2% decrease in the total radiation dose and a 37.1% decrease in radiation dose per run. The protocol was associated with a 41.6% decrease in the total radiation exposure and a 39.5% decrease in exposure per run.

**Conclusions:** Radiation reduction protocols can be readily applied to neuroendovascular interventions without increasing overall fluoroscopy time and reduce radiation dose and exposure by 39.2% and 41.6% respectively. We strongly encourage all interventionalists to be cognizant of pulse rate and frame rate when performing routine interventions.

**Keywords** Chronic subdural hematoma, Endovascular procedures, Fluoroscopy, Meningeal artery, Neurosurgery, Radiation

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## INTRODUCTION

As the prevalence of neuroendovascular interventions increases, it is critical to mitigate unnecessary radiation for patients, providers, and health care staff. Radiation exposure results in a wide array of harmful effects including carcinogenesis, harmful epigenetic mutations and lifespan reduction.<sup>3)5-7)</sup> The magnitude of deterministic effects and likelihood of stochastic effects of radiation on health compound with increasing lifetime exposure, thus any reduction in radiation exposure minimizes health effects and risk for patients, providers, and other health care staff. “As Low As Reasonably Achievable” (ALARA) principles regarding radiation stewardship can be accomplished through a combination of:

- Consistent use of protective screens, lead aprons, thyroid guards, and other protective equipment
- Avoiding direct beam exposure, if possible
- Maximizing distance between staff and providers and x-ray source
- Minimizing distance between the patient and x-ray intensifier
- Collimator usage to limit stray radiation
- Consistent, established communication between staff regarding use of radiation

In addition to these principles, minimizing emitted radiation dosage by reducing frame and pulse rates amplifies the effects of the above practices to set a new standard for “reasonably achievable” radiation reduction in the operating suite.<sup>2)8)</sup>

Our group previously demonstrated the feasibility of reducing radiation dose and exposure during diagnostic angiography by reducing the default pulse and frame rates on our Siemens Artis Q biplane. We applied the same technique to reduce radiation dose and exposure for basic neuroendovascular interventions. For the purposes of this study, unilateral middle meningeal artery embolization was selected as an investigational procedure to assess safety, feasibility, and radiation dose and exposure through reducing pulse rate and frame rate during these interventions. In a continuing effort to

reduce patient and provider exposure to radiation, we conducted a retrospective quality review to understand the effects of lowering frame and pulse rates on patient outcomes when treated by middle meningeal artery (MMA) embolization.

## 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 were reduced from 15 p/s to 7.5 p/s and 7.5 f/s to 4.0 f/s respectively. We studied consecutive, unilateral middle meningeal artery embolizations treated with particles. Total radiation dose, radiation per angiographic run, total radiation exposure, and exposure per run were calculated. 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 17.0 (Stata Corp LP, College Station, Texas, US). Significance was defined as  $p < 0.05$ .

## RESULTS

A total of 20 consecutive, unilateral middle meningeal artery embolizations were retrospectively analyzed, 10 prior to the protocol change and 10 after (Table 1). Univariable analysis revealed that radiation dose (668 vs. 456.4 mGy,  $p = 0.005$ ), radiation dose per angiographic run (42.3 vs. 26.1 mGy,  $p < 0.001$ ), total radiation exposure (8897.3 vs. 5576 mGym<sup>2</sup>,  $p < 0.001$ ), and exposure per run (564.2 vs. 340 mGym<sup>2</sup>,  $p < 0.001$ ) were all significantly decreased after the protocol was implemented. Average patient BMI, fluoroscopy time, number of vessels catheterized, and number of angiographic runs did not differ between groups, demonstrating consistency in practice despite the change in protocol.

On multivariable log-linear regression adjusting for

**Table 1.** Dose and exposure differences with radiation reduction protocol

Factor	Before reduction protocol	After reduction protocol	p-value
Number of patients	10	10	
BMI, mean (SD)	27.6 (4.4)	23.2 (6.1)	0.08
Total radiation dosage (mGy), mean (SD)	668 (111.0)	456.4 (177.6)	0.005
Total exposure (mGym <sup>2</sup> ) mean (SD)	8825.8 (1841)	5576 (1699)	<0.001
Fluoroscopy time (minutes), mean (SD)	21.9 (9.7)	22.7 (7.0)	0.84
Total radiation dosage per fluoroscopy time (mGy/min), mean (SD)	34.5 (11.6)	22.72 (7.0)	0.003
Vessels catheterized, mean (SD)	2.0 (0.0)	2.0 (0.0)	
Total mGy per vessel catheterized (mGy), mean (SD)	334 (55.5)	228.2 (88.8)	0.005
Total exposure per run (mGym <sup>2</sup> ), mean (SD)	564.2 (148)	340 (72.7)	<0.001
Number of runs, mean (SD)	16.3 (4.0)	17.4 (5.7)	0.63
Total radiation dosage per run (mGy), mean (SD)	42.3 (9.6)	26.1 (6.5)	<0.001

SD, Standard Deviation

BMI, number of runs, vessels catheterized, and fluoroscopy time, the radiation reduction protocol was associated with a 39.2% decrease in the total radiation dose (95% Confidence Interval [CI] 15.5–62.9%,  $p=0.003$ ) and a 37.1% decrease in radiation dose per run (15.7–58.4%,  $p=0.002$ ). The protocol was associated with a 41.6% decrease in the total radiation exposure (18.6–64.6%,  $p=0.002$ ) and a 39.5% decrease in exposure per run (18.8–60.1%,  $p=0.001$ ).

## DISCUSSION

In continuation of our group's intentional efforts to reduce patient and provider radiation exposure which has harmful, long lasting health consequences, we extended our investigation of radiation pulse and frame rate reduction during interventional procedures following our demonstrated outcomes in diagnostic cerebral angiograms. Middle meningeal artery embolization is considered a safe and effective procedure for the treatment of chronic subdural hematoma, and while postoperative complications are low, provider use of fluoroscopy presents an opportunity for further improvement of both patient and provider longitudinal

safety. Reported fluoroscopy times for MMA embolization are 43.2 and 28.2 minutes via femoral and radial approaches, respectively.<sup>1)</sup> Our reported mean fluoroscopy times for diagnostic cerebral angiograms using the default settings and ALARA protocol were 9.3 minutes and 10.5 minutes, respectively ( $p=0.45$ ).<sup>8)</sup> This demonstrates that reduction in radiation pulse and frame rates do not result in lengthened procedure times and thus result in reduced doses and total exposures. Similarly, diagnostic quality of the angiograms was unaffected by reduced frame and pulse rates. Following ALARA principles, reductions in frame and pulse rates for longer, interventional procedures yield larger overall reductions in total radiation exposure.

We previously published a modified radiation protocol in diagnostic cerebral angiograms reducing pulse rate from 15 p/s to 7.5 p/s and frame rate from 7.5 f/s to 4.0 f/s.<sup>8)</sup> Application of this protocol to unilateral middle meningeal artery embolization procedures demonstrated no difference in patient outcomes while greatly reducing total radiation exposure and radiation dose, with no change in fluoroscopy time, number of vessels catheterized, or number of runs. Patient outcomes were identical between the control and experimental groups. There were no demonstrated differences in surgical

practice apart from the lowered radiation dose. As our group previously demonstrated with diagnostic cerebral angiograms, patient BMI correlates significantly with radiation exposure, and this effect is redemonstrated in unilateral middle meningeal artery embolization procedures.<sup>8)</sup>

Similar to diagnostic cerebral angiograms (DCAs), the lowest feasible limit of radiation exposure during MMA embolization is not currently known. Previous studies on adult head phantoms have demonstrated variable frame rates (VFR) can be utilized to yield a 40-42 fold reduction in radiation exposure.<sup>4)</sup> Schneider, et al. also explored VFR radiation reduction methods with 2f/s and 1f/s in arterial and venous phases, respectively, while maintaining sufficient diagnostic information, increasing to 4-6 f/s for high flow lesions.<sup>6)</sup> Comparison between studies with different VFR methodologies is challenging due to simultaneous modification of multiple variables. This presents an opportunity to standardize VFR methods for ALARA investigations moving forward.

Other variables exist that have yet to be properly studied for the purposes of radiation reduction. Outside of the parameters of the radiation frame and pulse rates, dose reduction of up to 50% has been demonstrated to decrease overall radiation exposure. Additionally, it has been shown that copper filtration and removal of the grid on the flat panel detector have a positive effect on radiation reduction. This demonstrates that programmable parameters are not the only variables which can be explored and presents an opportunity for collaboration with vendors to optimize device design in pursuit of ALARA principles. Our study has clearly demonstrated other areas of potential improvement for radiation reduction in the operating suite outside of diagnostic procedures. Similar to our DCA investigation's findings, default settings on fluoroscopy equipment used in interventional procedures expose patients, providers, and staff to unnecessary radiation without any clear benefit in procedural outcome.

## CONCLUSIONS

Radiation reduction protocols can be readily applied to neuroendovascular interventions without increasing overall fluoroscopy time and reduce total radiation dose and exposure by 39.2% and 41.6% respectively. We strongly encourage all interventionalists to be cognizant of pulse rate and frame rate when performing routine interventions to avoid unnecessary radiation towards patients, providers, and health care staff.

## Disclosures

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

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