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Practical Radiation Dose Using Modern and Aged Angiographic Equipment

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Abstract

Background— Replacement of angiographic capital equipment is costly, particularly in resource-limited settings where aging platforms remain in clinical use. Advances in detector technology, image processing, and automated dose control have substantially reduced radiation exposure in modern systems, yet real-world generational comparisons remain limited.

Methods— This retrospective single-center study evaluated 363 neurointerventional procedures performed between September 2023 and February 2024 at The Queen's Medical Center. Cases were completed on either a 17-year-old Philips Allura Xper FD10/10 (n=189) or a 1-year-old Siemens Artis Icono (n=174). Procedures were categorized as diagnostic angiography, embolization, or stroke intervention. Radiation exposure was assessed using system-reported cumulative air kerma. Medians and interquartile ranges were compared using Wilcoxon rank-sum testing.

Results— Across all procedures, median cumulative air kerma was significantly higher on the older system (1267 [902–1827] mGy) compared with the newer platform (410 [251–677] mGy; p<0.001), representing an approximately three-fold reduction following modernization. Diagnostic angiography demonstrated the largest relative decrease (1085 vs 280 mGy), followed by embolization (1847 vs 639 mGy) and stroke intervention (1382 vs 371 mGy) (all p<0.001). Clinically relevant thresholds were exceeded more frequently on the older system: 17.5% of cases surpassed 2 Gy versus 0.6% on the newer platform, while no procedures on the modern system exceeded 3 Gy.

Conclusions— Contemporary angiographic technology was associated with three- to four-fold reductions in radiation exposure across neurointerventional procedures, underscoring the substantial safety benefits of equipment modernization.

Keywords— Radiation dose, biplane angiography, air kerma, equipment modernization, patient safety.

Abbreviations— ALARA, as low as reasonably achievable; Gy, gray; mGy, milligray; IQR, interquartile range.

KEY MESSAGES

What is already known on this topic – Radiation exposure is an important safety consideration in neurointerventional procedures, and older angiography systems may contribute to greater radiation burden due to limitations in imaging and dose-reduction technology.

What this study adds – In 363 neurointerventional procedures performed using a 17-year-old versus a 1-year-old biplane angiography system, median cumulative air kerma was approximately three-fold lower with the newer system (1267 vs 410 mGy; p<0.001). Radiation exposure was lower across diagnostic angiography, embolization, and stroke intervention, with substantially fewer procedures exceeding 2 and 3 Gy on the newer system.

How this study might affect research, practice, or policy – These findings support consideration of angiographic equipment age and technology when evaluating radiation exposure and patient safety. The results may inform equipment replacement decisions and future studies evaluating the clinical and economic impact of angiographic system modernization.

BACKGROUND

Replacing capital equipment such as biplane angiography units is expensive for hospital systems. This is especially true in the developing world, where installation of second-hand equipment may be the most practical low-cost option. The technology of dose reduction has evolved significantly over time, and measured clinical dosing provides a direct method of assessing radiation exposure to patients and providers in

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TABLE 1: Radiation dose metrics by angiography system and procedure type. Median air kerma values are presented as mGy (interquartile range, IQR). Additional metrics include maximum recorded dose and the proportion of cases exceeding clinically relevant radiation thresholds (>2 Gy, >3 Gy, and >5 Gy). Comparisons between the 17-year-old and 1-year-old systems were performed using unpaired Wilcoxon rank-sum testing, with p-values reported for each procedure category.

Procedure Type	System	N	Median (IQR) mGy	Maximum Dose (mGy)	% >2 Gy	% >3 Gy	% >5 Gy	p-value
All Cases	17-yr	189	1267 (902–1827)	7652	17.5	6.3	1.1	**<0.001**
	1-yr	174	410 (251–677)	2090	0.6	0	0	
Diagnostic	17-yr	95	1085 (786–1412)	7652	5.3	1.1	1.1	**<0.001**
	1-yr	63	280 (171–461)	1416	0	0	0	
Embolization	17-yr	52	1847 (1229–2459)	6765	36.5	19.2	1.9	**<0.001**
	1-yr	60	639 (421–939)	1944	0	0	0	
Stroke Intervention	17-yr	42	1382 (968–1830)	3028	21.4	2.4	0	**<0.001**
	1-yr	51	371 (255–595)	2090	2.0	0	0	

practice.

Fluoroscopy-guided neurointerventional procedures are integral to the management of cerebrovascular diseases, providing diagnostic and therapeutic benefits with reduced perioperative risk compared to open surgery.[1,2] While the clinical benefits are significant, these procedures expose both patients and staff to ionizing radiation, which carries potential risks including tissue injury and increased lifetime cancer risk with cumulative exposure.[3-8] Additionally, though the harmful effects of high-dose radiation are well-established, the stochastic risks associated with low-dose exposure remain uncertain, particularly in the diagnostic and interventional range where no clear threshold for carcinogenic risk has been defined.[8] This uncertainty reinforces the continued application of the As Low As Reasonably Achievable (ALARA) principle as the foundation of radiation protection practices.[9]

One often-overlooked contributor to radiation burden is the age and technological capability of imaging hardware. Older systems may lack modern features such as real-time image processing, automated exposure control, and optimized detector design, resulting in higher radiation output to maintain diagnostic performance.[10] In contrast, newer angiography platforms incorporate these advancements, reducing radiation dose without compromising image quality.[11-14] Other factors such as adherence to best practices and operator experience also contribute to radiation exposure in neurointerventional procedures.[15]

In 2023, our center acquired a 1-year-old biplane angiography system alongside an existing 17-year-old unit, an early-generation platform in operation for over a decade. The new unit incorporated contemporary dose management features providing an opportunity to assess the practical impact of generational equipment upgrades on radiation exposure during routine neurointerventional procedures. In this study, radiation dosage was compared across three case categories: diagnostic angiography, embolization, and stroke intervention. Results were evaluated in the context of published dose benchmarks to inform the role of equipment modernization in reducing radiation burden and enhancing procedural safety.[16]

METHODS

This retrospective study was performed at a single institution and complied with HIPAA requirements. The biplane angiography systems included a 17-year-old Philips Allura Xper FD10/10 and a 1-year-old Siemens Artis Icono. Similar neurointerventional imaging protocols were used for both units, including an initial digital subtraction angiography frame rate of 2 frames per second followed by 1 frame per second during venous phases, with a fluoroscopic pulse rate of 7.5 frames per second. Magnification and pulse rate adjustments were applied according to operator preference, with the same operators performing procedures on both systems. Radiation exposure was assessed for patients undergoing angiography for diagnostic evaluation, stroke intervention, or embolization procedures. Total radiation dose was calculated as the sum of anteroposterior and lateral air kerma.

All patients undergoing procedures from September 2023 through November 2023 using the Philips Allura Xper FD10/10 were included in the 17-year-old arm, and all patients undergoing procedures from December 2023 through February 2024 using the Siemens Artis Icono were included in the 1-year-old arm. Radiation dose was measured as system-reported cumulative air kerma for each procedure. Neurovascular cases were performed by mid-career neurointerventionalists with more than 15 years of experience, and peripheral cases were performed by fellowship-trained peripheral interventionalists with 4 to 25 years of experience.

Procedures were categorized into four groups for analysis: Diagnostic, Embolization, Stroke Intervention, and All Cases. Diagnostic procedures did not involve device deployment or therapeutic intervention. Embolization procedures included coiling, flow diversion, intrasaccular treatments, and stent-

assisted coiling. Stroke Intervention included all mechanical thrombectomy procedures regardless of technique.

Data were assessed for normality using Shapiro-Wilk testing. Given the non-normal distribution of radiation dose, values were summarized using medians and interquartile ranges (IQRs). Comparisons between systems were performed using an unpaired Wilcoxon rank-sum test.

RESULTS

A total of 363 neurointerventional procedures were included in this expanded analysis, comprising 189 and 174 cases performed on the 17-year-old and 1-year-old biplane angiography systems, respectively. Radiation exposure was assessed using cumulative air kerma, reported in milligray (mGy).

Across all procedures, the median cumulative air kerma for the 17-year-old system was 1267 (902–1827) mGy compared to 410 (251–677) mGy for the 1-year-old system ($p < 0.001$), representing an approximately three-fold reduction in radiation exposure following system modernization. Overall, the older system delivered between three- and four-fold higher radiation doses across procedure types. A summary of radiation dose metrics by system and procedure type is provided in Table 1.

All procedure types demonstrated statistically significant reductions in air kerma across cumulative, anteroposterior, and lateral views ($p<0.001$ for all comparisons). Diagnostic angiography exhibited the largest relative reduction, with median air kerma decreasing from 1085 (786–1412) mGy to 280 (171–461) mGy, corresponding to nearly a four-fold decrease. Embolization procedures demonstrated a reduction from 1847 (1229–2459) mGy to 639 (421–939) mGy, representing approximately a three-fold decrease. Stroke intervention procedures showed a decline from 1382 (968–1830) mGy to 371 (255–595) mGy, again reflecting nearly a four-fold reduction. Distributions of cumulative, lateral, and anteroposterior (AP) radiation dose by system and procedure type are illustrated in Figure 1.

Projection-specific analysis demonstrated consistent reductions in both anteroposterior and lateral air kerma with the newer system, indicating that dose savings were not confined to a single imaging plane but reflected global improvements in dose management across fluoroscopic projections.

Evaluation of clinically relevant dose thresholds further highlighted differences between systems. The 17-year-old platform demonstrated substantially higher proportions of procedures exceeding 2 Gy and 3 Gy thresholds, particularly among embolization procedures, whereas threshold exceedance was rare with the 1-year-old system. Across all cases, 17.5% of procedures performed on the older system exceeded 2 Gy compared with 0.6% on the newer system. Similarly, 6.3% of older-system cases exceeded 3 Gy, whereas no procedures on the newer system reached this level. Exceedance of the 5 Gy threshold was uncommon overall and observed only in the older system. These findings are summarized in Table 1 and illustrated in Figure 2.

DISCUSSION

The results of this study demonstrate a meaningful reduction in patient radiation exposure following the transition from the 17-year-old to the 1-year-old biplane angiography system. Across all neurointerventional procedures, radiation dose decreased by approximately 68%, with the greatest reduction observed in diagnostic cases, where median air kerma fell by approximately 74%, constituting reduction by a factor of 3.9. These reductions are substantial and clinically relevant, particularly in diagnostic angiography, which typically involves shorter procedural times and less complexity, suggesting that even routine cases may benefit from modern dose-reducing technologies. Unlike prior neurointerventional studies focused primarily on procedural technique, dose benchmarking, or protocol optimization,[17-19] this work evaluates the clinical impact of replacing an aging biplane angiography system, offering real-world evidence that technological modernization alone may substantially reduce radiation exposure.

For patients, such reductions carry the potential for decreased stochastic risk, obviating concern for radiation-induced malignancies, which holds specific importance given the cumulative nature of radiation exposure throughout one's lifetime.[4] Procedural staff also benefit indirectly, as lower patient dose generally correlates with reduced scatter radiation in the operator environment, mitigating occupational hazards such as cataract formation and skin damage over time.[20-22] Given the multi-fold reductions observed across procedure types in this study, even modest per-case dose decreases may translate into meaningful cumulative risk reduction over the course of a patient's lifetime and across years of operator practice.

These reductions are due to substantial technological improvements in biplane angiography systems over the past 17 years, and are attributed to advances in hardware, software, and dose management protocols. The replacement of image intensifiers with flat panel detectors offers the advantage of more consistent and clearer imaging with the absence of geometric distortion and vignetting at a lower patient and occupational radiation.[23] Modern X-ray tubes use flat electron emitter cathodes instead of the coiled wire emitters in older models, which support higher tube currents and power limits, optimize focal spot sizes, and shorten pulse length capabilities that reduce blurring in moving anatomy scenes.[24] Such hardware advancements improve image efficiency while lowering radiation dosage.[23,24] Additionally, software upgrades such as improved noise-reducing algorithms and image quality enhancements have demonstrated improved image processing at lower radiation settings.[25] The combination of these advancements with the capabilities of automatic dose rate control, which automates and modulates the selection of X-ray factors in real time based on procedural requirements and patient thickness, allows for significant reductions in radiation dosage and improved imaging and efficiency in modern biplane angiography systems.[26] Consistent reductions

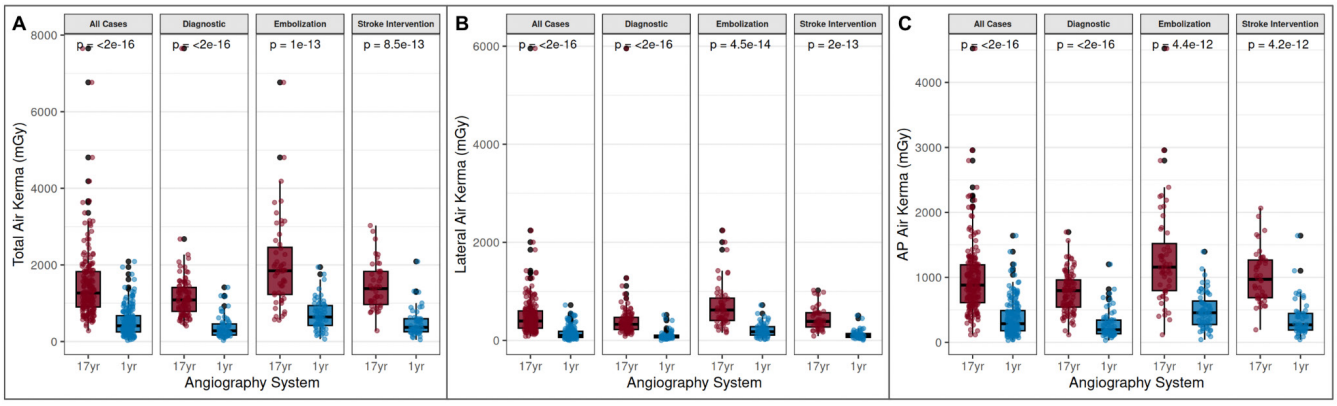


FIGURE 1: Distribution of radiation dose by angiography system and procedure type.
Boxplots comparing air kerma administered during neurointerventional procedures performed on a 17-year-old versus a 1-year-old biplane angiography system. (A) Total radiation dose, (B) lateral projection dose, and (C) anteroposterior (AP) projection dose. Panels are stratified by procedure indication (All Cases, Diagnostic, Embolization, and Stroke Intervention). Each point represents an individual patient. Boxes denote the interquartile range (IQR) with the median indicated and whiskers extending to distribution limits. Statistical comparisons between systems were performed using unpaired Wilcoxon rank-sum testing, with p-values displayed within each panel. Data reflect cumulative procedural experience at The Queen's Medical Center, Honolulu, HI.

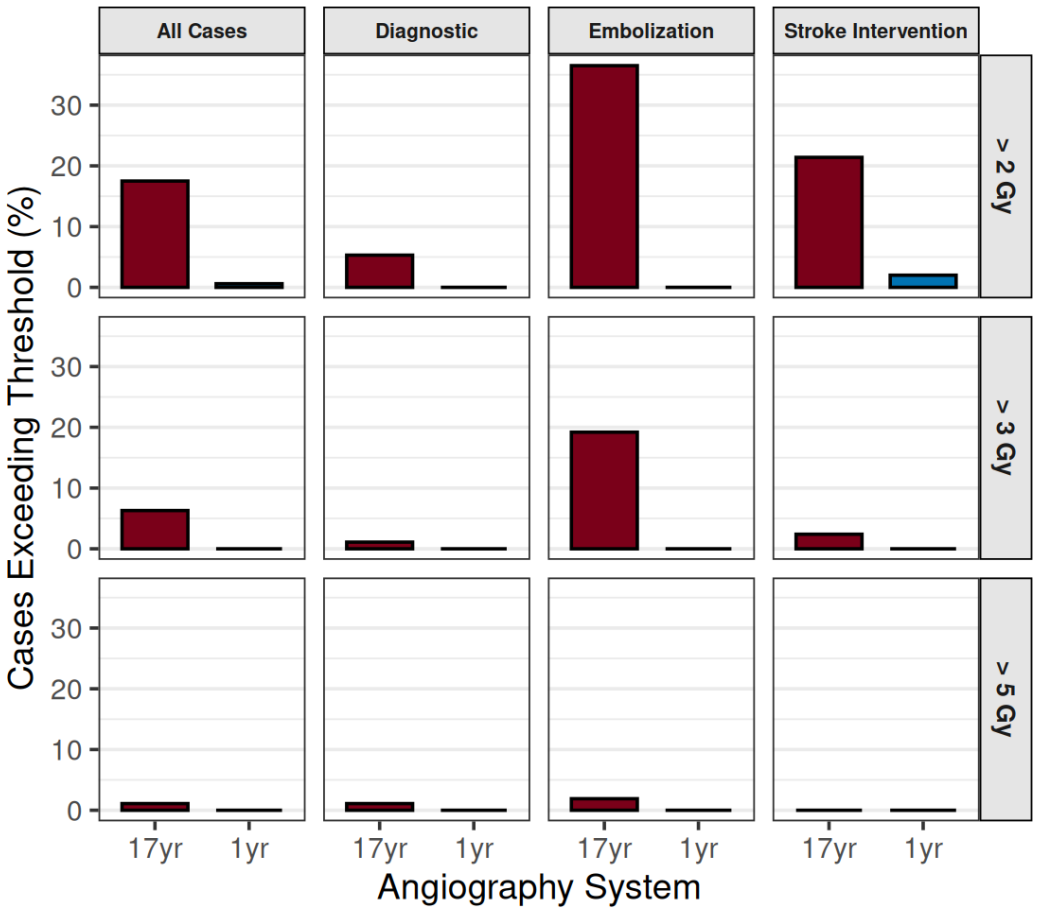


FIGURE 2: Proportion of procedures exceeding clinically relevant radiation dose thresholds by angiography system and procedure type. Bar plots illustrate the percentage of neurointerventional procedures exceeding cumulative air kerma thresholds of >2 Gy, >3 Gy, and >5 Gy, stratified by procedure indication (All Cases, Diagnostic, Embolization, and Stroke Intervention). Comparisons are shown between a 17-year-old and a 1-year-old biplane angiography systems. Percentages represent the proportion of total cases within each procedure category. Data reflect cumulative procedural experience at The Queen's Medical Center, Honolulu, HI.

were observed across both anteroposterior and lateral projections, suggesting that improvements were not limited to a single imaging plane but reflected global advances in radiation efficiency with newer systems.

The findings in this study underscore the role of imaging system age as a determinant of radiation burden. Older platforms, such as the 17-year-old Philips Allura Xper FD10/10 used in this study, often lack the advanced image processing algorithms, real-time dose modulation, and optimized detector technology that characterize newer systems.[11,14] Over time, hardware degradation, such as X-ray tube wear and detector inefficiency, can further exacerbate dose creep as systems struggle to maintain image quality.[27] This phenomenon likely contributed to the significantly higher doses seen in the older system despite identical procedural teams and techniques, emphasizing that even experienced operators cannot fully compensate for technological limitations. In addition, the older platform demonstrated substantially higher rates of procedures exceeding clinically relevant radiation thresholds, particularly among embolization cases, whereas threshold exceedance was rare with the newer system. This observation further supports the clinical relevance of modernization beyond reductions in median dose alone.

From an operational standpoint, the case for system upgrades extends beyond radiation safety. Modern platforms not only reduce dose but also offer workflow efficiencies, reduced procedure times, and enhanced imaging capabilities that can improve diagnostic confidence and therapeutic precision.[28,29] While the capital cost of replacing an angiography suite is substantial, these long-term gains – including reduced patient risk, improved operator safety, and potential savings from fewer complications or re-interventions – may offset the initial expense. In high-volume centers, these improvements can directly translate into meaningful financial and clinical value.

Given these findings, institutions relying on aging angiography equipment should consider prioritizing upgrades, particularly in departments performing neurointerventional or other high-radiation procedures. Adherence to the ALARA principle necessitates not only procedural vigilance but also investment in technology that supports dose optimization at a systems level. Future work should examine the durability of these dose reductions across a wider range of procedures and patient populations and explore cost-benefit analyses to guide equipment replacement policies.

CONCLUSIONS

This study demonstrates the practical radiation impact of modern angiographic equipment equipped with state-of-the-art dose reduction, resulting in substantial reduction of absorbed dose for both patients and healthcare providers. Doses were higher in the older unit by a factor of approximately 3-4 times depending on procedure type. The findings support the importance of modernizing aging angiography equipment to optimize radiation safety for both patients and staff, consistent with the widely-employed ALARA principle where possible. Institutions utilizing older systems should consider the clinical and operational benefits of system replacement as part of their long-term strategy to limit radiation exposure, improve procedural quality and patient care.

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