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Variability in radiation dose and image quality: A comparison across fluoroscopy-system vendors, generations of equipment and institutions

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Abstract

Objectives: To evaluate differences in radiation dose and image quality across institutions, fluoroscope vendors and generations of fluoroscopes for pediatric cardiac catheterization.

Background: Increased recognition of the potentially harmful effects of ionizing radiation has spurred technological advances in fluoroscopes, as well as increased focus on optimizing fluoroscope performance. There is currently little understanding of variability in the dose-image quality relationship across institutions, fluoroscope vendor and/or generation of equipment.

Methods: We evaluated latest generation fluoroscopes from Phillips, Siemens, GE and Toshiba, and an older generation Phillips fluoroscope (release date 2003) at three different institutions. Radiation dose was measured using an anthropomorphic dose-assessment phantom with effective dose in mSv estimated from Monte Carlo simulations. Image quality phantom images were scored on a 12-point scale by three blinded reviewers.

Results: Fluoroscope effective doses ranged from 0.04 to 0.14 mSv/1000 pulses for fluoroscopy with associated composite image quality scores ranging from 8.0 ± 0.6 to 10.4 ± 1.3 . For cineangiography, effective doses ranged from 0.17 to 0.57 mSv/1000 frames with image quality scores ranging from 10.1 ± 0.3 to 11.1 ± 0.3 . There was modest correlation between effective dose and image quality ($r=0.67$, $p=0.006$). The older generation fluoroscope delivered consistently higher doses than the newer generation systems (2.3 to 3.5-fold higher for fluoroscopy; 1.1 to 3.4-fold higher for cineangiography) without appreciable differences in image quality.

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Conclusion: Technological advances have markedly improved fluoroscope performance. Comparing latest generation systems across vendors and institutions, we found variability in the dose-IQ relationship and speculate that this reflects both equipment and institutional optimization practices.

Keywords

Image quality; effective dose; fluoroscopy; institutional variability

Introduction

In children with heart disease, fluoroscopically guided cardiac procedures account for more cumulative ionizing radiation exposure than all other imaging procedures combined (1–3). Children are more sensitive to the harmful effects of ionizing radiation due to their increased tissue sensitivity, and longer anticipated lifespan during which harmful effects can accrue (4–6). For these reasons stakeholders, including interventional pediatric cardiologists and fluoroscope manufacturers, are increasingly recognizing the critical importance of improving radiation safety during fluoroscopically guided procedures (4,7–11). Increased recognition has led to new advances in fluoroscopic hardware and software aimed at reducing radiation dose, as well as increased attention to equipment and procedural optimization to facilitate lower dose imaging in children.

While breakthroughs in dose reduction have undoubtedly improved the safety of pediatric fluoroscopically guided cardiac procedures, there will always be an inverse relationship between radiation dose and image quality. Efforts to reduce radiation dose should not impact image quality to an extent that compromises either diagnostic capability or procedural safety (9). Currently there are no universally accepted practice standards dictating appropriate image quality during pediatric cardiac catheterization, and there is little understanding of variability in the dose-image quality relationship across institutions, equipment vendors or even generations of fluoroscopy equipment.

Our objective was to better understand variability in the various image quality and radiation dose parameters. Using dose-assessment and image quality phantoms, we evaluated image quality and radiation dose for fluoroscopy and cineangiography across: 1) four different fluoroscopy equipment vendors (Phillips, Toshiba, Siemens and General Electric [GE]); 2) three different pediatric institutions all with recent upgrades in their fluoroscopy equipment and 3) two generations of Phillips fluoroscopy equipment.

Methods

Fluoroscopic systems and institutions

Table 1 summarizes the fluoroscopic systems tested. Assessments were performed on the latest generation (as of 06/2016) fluoroscopic equipment from each of the major pediatric fluoroscopic equipment vendors including the Phillips Allura Clarity (received FDA clearance in 2013), Siemens Artis Q (2013), Toshiba Ultimix-I (2015) and the GE Innova IGS (2013) systems. Additionally testing was performed on an older generation Phillips

Allura Xper FD10/10 system (2003). Three institutions, all with recent upgrades to their fluoroscopy equipment, participated in this analysis: Duke University Children's Hospital, Monroe Carell Jr. Children's Hospital at Vanderbilt and LeBonheur Children's Hospital. Assessment of the GE system was performed at the GE testing laboratory in Buc, France as we could not coordinate an institutional assessment at a pediatric institution with a recent installation of the GE Innova IGS fluoroscopy system. As part of the conditions of the assessment, engineers at the testing laboratory agreed in advance to the dose and image quality testing parameters that we stipulated and allowed our investigator to independently verify the system setup including the use of an ion chamber to confirm that appropriate kerma values were reported.

Dose Assessment

An ATOM family anthropomorphic phantom (CIRS, Norfolk, VA) representing a newborn (51cm, 3.5kg, thorax dimension 9×10.5 cm) was used for dose simulations. This phantom is designed specifically for radiation dose assessment and is manufactured using tissue/organ equivalent epoxy resins (including bone density formulated to represent the appropriate bone age of the phantom) with linear attenuation within 1% for bone and soft tissue and 3% for lung tissue at photon energies from 30 keV to 20 MeV.

Testing of the various fluoroscopes was performed using the fluoroscopic hardware and configuration specifications in clinical use at the various institutions at the time of evaluation. For all systems we used the lowest available dose mode and we tested the neonatal imaging parameters previously configured for each system. We did not make any attempt to optimize the various fluoroscopes beyond their already configured "clinical setup". As the GE fluoroscope was tested at the GE testing laboratory, we relied upon the hardware and software configuration of the system without further optimization. For all imaging, a "standard operating technique" was defined. A baseline phantom image was recorded at our first institutional assessment and this image was replicated at each of the remaining institutions to ensure an identical imaging field-of-view. The phantom was positioned at the imaging isocenter and cameras were positioned by a trained pediatric interventional cardiologist to optimally simulate typical imaging views. Peripheral collimators were used for all of the imaging sequences to limit scatter effects and to fine tune the imaging field of view. Collimators were set to the same width for all imaging using the baseline phantom image as a reference. We used similar magnification settings at each of the institutions and we used the infant / child fluoroscopy and cineangiography protocols in use at the institution at the time of the assessment. Fluoroscopy and cineangiography were performed with the table height adjusted to allow for imaging in the lateral position and using a source-to-image distance of 93cm (i.e. lowest possible camera height). For consistency and to facilitate comparisons, pulse rates of 15 pulses per second were used for fluoroscopy and 15 frames per second for cineangiography. The pulse width was not manipulated so as to allow comparisons under "usual" imaging conditions. The anti-scatter grid was left in place for all of the assessments. All imaging was performed for 1 minute of continuous exposure for fluoroscopy and 10 seconds of continuous exposure for cineangiography. For each imaging sequence we recorded radiation-related output values from the fluoroscopy system including kVp, millamperes (mA), and air kerma (mGy).

Monte Carlo dose simulations—Organ/tissue doses and cumulative effective doses were estimated from Monte Carlo simulations using PCXMC (version 2.0) simulation software (STUK, Helsinki Finland) (12). PCXMC estimates radiation dose to organs and the whole body using a mathematical phantom. It yields dosimetric estimates of primary radiation from measurements and manufacturer specifications, and of scatter using Monte Carlo calculations. The methodology has been previously published and validated, and a comprehensive description is provided on the website of STUK, the Radiation and Nuclear Safety Authority of Finland (http://www.stuk.fi/sateilyn-hyodyntaminen/ohjelmat/PCXMC/en_GB/pcxmc/). Data input into the PCXMC simulation software included the phantom age, height and weight, as well as the imaging parameters including: 1) beam shape, 2) beam position over the thorax, 3) source to subject distance, 4) subject to receptor distance, 5) camera angles, 6) spectral filtration (e.g. copper, aluminum) and 7) air kerma at the interventional reference point (based on system reported values). Kerma values were adjusted to account for differences in the imaging isocenter for the various systems. Effective doses were estimated using the weighting factors of the International Commission on Radiological Protection (ICRP) in its 2007 recommendations, i.e. ICRP Publication 103 (1). Weighted equivalent doses were determined for all organs for which individual weighting factors are assigned in ICRP 103. Dose estimates of effective dose were determined by summing these weighted equivalent doses, as well as a weighted equivalent dose reflecting the “remainder organs”.

Image quality assessments

Image quality assessments were performed consistent with guidelines from the Society for Cardiac Angiography and Interventions using a CIRS Model 903 – Radiography Fluoroscopy QA Phantom. The phantom was placed on 1.75 inches of acrylic because testing with an ion chamber demonstrated that this thickness approximated the beam attenuation of the infant phantom. To test spatial resolution, the phantom test objects include high-resolution copper mesh targets from 12 – 80 lines per inch. To test low contrast detectability, the phantom included two separate sets of contrast-detail test objects. The phantom was positioned in the center of the imaging field-of-view with the image collimated on all sides to reduce scatter and improve contrast. Three second fluoroscopy-save and cineangiography acquisitions were stored in DICOM format. In addition fluoroscopy-save and cineangiography acquisitions of the infant dose phantom were stored. The images were subsequently assigned a random number identifier. All images were rated by three blinded pediatric cardiologists. The cardiologists performed the image quality assessments on a monitor in a standard pediatric catheterization laboratory with lighting conditions simulating typical procedural conditions. Each was asked to score the minimal line per inch and contrast-detail test object that could be differentiated. The image quality phantom consists of nine different parameters for each of these measures (i.e. nine different wells containing contrast of varying concentrations and nine different objects, each with an increasing number of lines per square inch). Reviewers were instructed to give mid-range estimates (e.g. 4.5 / 9) to provide greater differentiation in scores. The scores for each parameter were combined to provide a composite image quality score on an 18-point scale. The reviewers also provided a global assessment of anthropomorphic phantom image quality.

Image quality assessments at standardized effective dose

To compare image quality of the latest generation systems at relatively comparable doses, we performed phantom imaging using different fluoroscopic and cineangiographic imaging modes (i.e. by manipulating the pre-programmed dose modes for each fluoroscope). Effective doses for each of these images were calculated using the same approach as summarized above. We then selected image acquisitions for each fluoroscope with similar doses per pulse / frame. Still frames images for these acquisitions were scored by the blinded reviewers using the same objective approach outlined above (minimum percent contrast and line space differentiation). Reviewers also provided a separate subjective ranking of image quality for the dosimetry phantom based on their visual assessment of the still frame image.

Institutional variability

Assessments summarized above use standardized frame rates (15 frames per second) and magnification settings to provide the best “apples to apples” comparison of fluoroscope performance. However, this approach does not account for variability in imaging approach. To provide a reasonable estimate of how variability in imaging approach might impact procedural doses, we surveyed centers regarding their typical frame rates and magnification settings for neonatal procedures for both fluoroscopy and acquisitions. Using the survey responses, we then repeated phantom assessments and Monte Carlo simulations to estimate expected procedural doses for a simulated diagnostic catheterization procedure consisting of 20 minutes of fluoroscopy exposure and four biplane cineangiographic acquisitions of 4 seconds each.

Statistical analysis

Statistical analysis was performed using SPSS 22.0 (IBM, Chicago, IL). Continuous data is presented as mean $\pm$ 1 SD. For effective dose estimates, and error % was reported to represent statistical uncertainty from the Monte Carlo simulation. Correlations between variables were determined using the Spearman rank order correlation coefficient. Cronbach’s alpha test was used to assess inter-rater reliability between the three image quality reviewers. All tests of significance were two-tailed; a P value of less than 0.05 was considered to indicate significance.

Results

Effective dose and Image Quality

Table 2 summarizes dose rates and image quality scores for fluoroscopy and cineangiography for the various fluoroscopes and institutions. When comparing across the latest generation systems, effective doses were relatively similar, ranging from 0.04 to 0.06 mSv/1000 pulses across all four vendors. In contrast, the older generation Phillips Allura system had 2.0 to 3.5-fold higher doses (0.14 mSv/1000 pulses). For acquisitions, dose rates for the newer generation systems ranged more widely from 0.17 mSv/1000 frames for the Phillips Clarity system to 0.52 mSv/1000 frames for the Toshiba Ultimix system (notably the Toshiba Ultimix system had the highest image quality score, see below for more details).

Once again dose rates for the older generation Phillips Allura system were higher than all of the other systems at 0.57 mSv/1000 frames.

With respect to image quality, there was good to excellent inter-rater reliability between the three reviewers with an overall reliability score of 0.87 (95% CI 0.72–0.94). Mean composite image quality scores for fluoroscopy ranged from 8.0 ± 0.6 for the Siemens Artis system to 10.4 ± 1.3 for the Toshiba Ultimix system. For acquisitions, mean composite scores ranged from 10.1 ± 0.3 for the Siemens Artis system to 11.2 ± 0.3 for the Toshiba Ultimix system. There was modest correlation between dose and image quality (Pearson correlation coefficient = 0.67, $p = 0.006$) suggesting that the differences in image quality were not entirely related to differences in delivered dose.

Institutional variability

In general, institutions reported using similar baseline imaging frame rates and magnification settings (Table 3). The two exceptions were: 1) institution C (Toshiba Ultimix) preferred fluoro-save mode instead of cineangiography for neonatal acquisitions; and 2) institution A used pulse and frame rates of 15 per second with their older generation Phillips Allura system as the system was not programmed to permit lower pulse / frame rates. Simulated diagnostic catheterization procedures (20 minutes of fluoroscopy time + four biplane acquisitions) are summarized in Figure 1. For latest generation systems procedural doses were very low, ranging from 0.29 to 0.48 mSv. However, the estimated procedural dose for the older generation Phillips Allura Xper system was substantially higher at 2.81 mSv. This increased dose reflects both increased dose per pulse / frame, as well as higher procedural pulse / frame rates.

Image quality comparisons at standardized effective dose

Selected acquisitions with similar doses per pulse/frame rate (range 1.7 to 2.6×10^{-4} mSv), and associated doses/image quality scores are displayed in Figure 2. Objective evaluation of contrast detail and line per square inch differentiation were relatively similar across the four vendors (Figure 2). The Allura Clarity system had the highest objective evaluation however all three reviewers subjectively considered the Toshiba Ultimix image as the highest quality followed by the Allura Clarity, GE Innova and then the Siemens Artis. Reviewers agreed that there was little difference in image quality across the four systems.

Discussion

This is the first analysis comparing variability in radiation dose and image quality across institutions and vendors for fluoroscopes used for pediatric cardiac catheterization. The most striking finding is the substantial reduction in dose achieved with the newer generation fluoroscopy systems when compared to the older generation Phillips Allura Xper system. While there was also some variability across vendors when comparing the newer generation systems, the differences were relatively smaller and may be partially or completely related to institutional system optimization rather than differences in hardware performance.

The doses that we estimate for a simulated cardiac catheterization procedure using the latest generation fluoroscopes (0.29 to 0.48 mSv depending on equipment vendor) are six to ten-

fold lower than the previous generation Phillips Allura Xper system (2.81 mSv), which received FDA clearance in 2003. These reductions reflect technologic improvements in fluoroscope hardware and software algorithms, but also dose reductions of ~ 2-fold due to lower pulse/frame rates with the newer generation systems. Of note, it is feasible to use lower pulse/frame rates with the older generation Phillips Allura system but there was no configured mechanism for doing this on the system that we tested. In contrast, the newer generation systems all incorporate easy to use toggles to accommodate rapid switching between a wider range of pulse / frame rates. Taken together, the hardware / software advances of latest generation systems, as well as their more user-friendly optimization features, result in the substantial reductions in radiation dose that we report. Our data may be useful to providers using older generation technology as a means to justify institutional fluoroscope upgrades.

When comparing the latest generation fluoroscopes across vendors, there were smaller, but nonetheless meaningful differences in both dose and image quality. These differences accurately reflect site variability in system performance but, without knowledge of the proprietary hardware specifications and software configurations for any given system, it is difficult to know if this is due to hardware performance versus differences in system optimization. Fluoroscope optimization is critically important in dose management, particularly for fluoroscopes used for pediatric imaging (9,13). No fluoroscope is “out of the box” ready for pediatric imaging and extensive optimization is always necessary. Laskey et al. previously assessed fluoroscopes across 20 different adult cardiac catheterization laboratories (14). They found substantial variability in dosages across institutions (four to six-fold differences in fluoroscopy doses depending on body habitus). They were evaluating a relatively wide range of fluoroscope modernity. For example, in their analysis, some of the systems tested were still using image intensifiers instead of flat panel receptors. Our data are similar when comparing across generations of equipment but we found less variability when comparing same generation equipment. Laskey et al. also found a relatively inconsistent relationship between dose and spatial resolution for the different fluoroscopes that they tested. Some systems achieved high spatial resolution at low dose rates while others demonstrated relatively higher doses yet low spatial resolution. We found moderate correlation between dose rates and image quality scores. This finding indicates that factors other than delivered dose impact image quality. Unfortunately, it is beyond the scope of our analysis to speculate on what these factors are, particularly given the proprietary nature of the technology.

It is also notable that there was substantial variability in image quality across institutions. In 2001 a working group convened by the Society for Cardiac Angiography and Interventions (SCAI) provided recommendations for phantom-based image quality assessment of fluoroscopes (15). We followed the recommended approaches for our assessments and our data provide the first published estimates of image quality for pediatric cardiac catheterization. Unfortunately, there are no current image quality standards or benchmarks that providers can reference when optimizing their imaging systems. Image quality is always in the “eye of the beholder”. Nonetheless, it would be helpful if providers could reference benchmark data to guide system set-up. Our data from only three institutions are not sufficient, but may provide a useful starting point.

Finally, it is reassuring that when using latest generation equipment, a procedure with 20 minutes of fluoroscopy time and four biplane cineangiograms can be performed with effective doses substantially below 0.5 mSv. At a recent NIH-NHLBI/NCI-sponsored think tank evaluating dose thresholds for cardiac imaging, doses ≤ 3 mSv were deemed “very low” (16). Indeed the estimated annual background radiation exposure to an individual living in the United States is ~ 3 mSv (17). Nonetheless, providers should remain vigilant in their efforts to reduce ionizing radiation exposure as our testing was performed under optimized imaging conditions (collimated, low magnification settings, low camera height etc). We have previously demonstrated that failure to optimize imaging approach during cardiac catheterization can increase procedural doses by up to 8-fold (18). It is also important to note that the harmful effects associated with a given dose are substantially increased in a neonate when compared to an adult (17).

Strengths of our study include the use of a standardized process and approach for dose estimation and image quality assessment. By using an anthropomorphic phantom specifically designed for radiation dose estimation, we were able to tightly control imaging conditions for the most accurate comparisons across institutions. Moreover, our blinded assessment of image quality ensures the most fair and unbiased approach. However, we do acknowledge that our blinded scoring system has not been previously validated in any formal research setting although it is reassuring that inter-rater reliability between the three reviewers was good to excellent with an overall reliability score of 0.87 (95% CI 0.72–0.94). There are also several additional limitations to our approach. Most notably, we relied upon the typical institutional approach to imaging without any standardization of hardware / software imaging parameters. This allows a comparison of approaches across institutions but limits ability to identify the “best” vendor or fluoroscopic equipment. Our comparisons of institutional variability are also limited as we relied on “typical” imaging parameters from the respective institutions. Operators will often adjust their imaging approach depending on procedural conditions, and our methodology does not capture the influence of these “operator-dependent” manipulations on institutional variability. We also limited our assessment to neonatal phantom imaging. This was purely for practical reasons as the older phantoms are bigger and extremely difficult to transport between institutions. It is possible that our findings are specific to neonatal imaging and do not reflect imaging in older children and adolescents. Certainly these findings should not be applied to adults as system optimization will be vastly different. Additionally, the image quality measurements were conducted without anatomical (structural) noise and with simplistic targets, which may not adequately differentiate the benefits of advanced image processing across systems. Our image quality details were limited to anatomic imaging and did not consider factors such as device visibility which can be critically important for procedural safety. Indeed device manufacturers are increasingly recognizing this and designing devices so as to augment fluoroscopic visibility. Finally, we evaluated equipment at only three institutions and a testing laboratory. The travel and testing burden associated with these analyses was substantial and limited testing at additional sites. Although our testing at the GE laboratory does not represent typical “practice”, GE engineers did agree to a subset of baseline testing parameters (e.g. we used an ion chamber to verify system-reported dose rates) and we performed the phantom imaging under standardized conditions to prevent any unfair

manipulation of the fluoroscope performance. It is also notable that fluoroscopic vendors are continuously evolving their imaging equipment and the “latest generation” equipment that we tested is already being replaced with newer models (e.g. the Phillips Azurion line was recently launched worldwide).

In conclusion, in our analysis of institutional, vendor-specific and generational differences in fluoroscope performance for pediatric cardiac catheterization, we found that newer generation systems substantially outperform a system considered “state of the art” only a decade ago. We also noted meaningful differences in institutional dose and image quality. Although we are unable to delineate whether these differences represent hardware and/or software related differences across vendors versus differences in institutional optimization approaches, the differences are meaningful and highlight the need for further study.

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Table:	Phillips Xper	Phillips Clarity	Siemens Artis Q	Toshiba Ultimix	GE Innova
Institution	A	A	B	C	D
Fluoro Dose / 1000 frames	0.14 mSv	0.04 mSv	0.06 mSv	0.06 mSv	0.04 mSv
Fluoro Image Quality	10.3 ± 1.3	9.8 ± 0.3	8.0 ± 0.6	10.4 ± 0.8	9.5 ± 0.6
Cine Dose / 1000 frames	0.56 mSv	0.17 mSv	0.40 mSv	0.52 mSv	0.29 mSv
Cine IQ	11.1 ± 0.3	11.0 ± 0.5	10.1 ± 0.6	10.4 ± 0.8	10.6 ± 0.8

IQ scores represent means $\pm$ 1SD. Institutional imaging parameters used: 5/7.5fps for fluoro/cine respectively except for the older generation Phillips Xper system (tested at 15fps consistent with institutional practice). The institution using the Toshiba system uses fluoro-save for cine.

Figure 1:

Effective dose for a simulated neonatal cardiac catheterization. Typical baseline institutional imaging parameters (see Table 3) were used to estimate effective dose for a simulated procedure consisting of 20 minutes of Fluoroscopy time + four biplane acquisitions. Dose estimates reflect both hardware performance as well institutional optimization processes. For example, the institution using the older generation Phillips Xper system uses higher frame rates, while the institution using the Toshiba Ultimix system uses fluoro-save mode for acquisitions instead of cineangiography. Testing for the GE system was performed at the GE testing lab and imaging parameters were chosen by investigator consensus.

Figure 2.

Comparison of image quality at standardized effective doses. Four image acquisitions with similar doses per pulse / frame (1.7 to 2.6×10^{-4} mSv) were scored by blinded reviewers. Reviewer scores reflect objective assessment of the image quality phantom (lower panel) with respect to the minimum percent contrast visible to the reviewer, and the maximum line space resolution (measured in lines per square inch). A lower objective score for both variables represents better image quality. Reviewers were also asked to subjectively rate image quality for a still frame thoracic image of the dosimetry phantom (upper panel). For this latter score the images are rated from best (#1) to worst (#4).

Table 1.

Systems tested

Institution	Fluoroscope	Installation date	Receptor dimension	Detector
A	Philips Allura Xper 10/10	2004	10" × 10"	Flat panel
A	Phillips AlluraClarity	2014	10" × 10"	Flat panel
B	Siemens Artis Q	2014	8" × 8"	Flat panel
C	Toshiba Ultimeax	2013	8" × 8"	Flat panel
Test lab	GE Innova	2013	21cm × 21cm	Flat panel

Table 2.

Effective doses and composite image quality scores

Fluoroscopy						
Institution	Manufacturer	Imaging mode ¹	kVp	Air kerma (mGy)	Effective dose (mSv) per 1000 frames	IQ score ²
A	Philips AlluraXper	Neonate < 10lbs	64	1.10	0.14 ± 0.007	10.3 ± 1.3
A	Phillips AlluraClarity	Neonate < 10lbs (Low)	63	0.32	0.04 ± 0.002	9.8 ± 0.3
B	Siemens Artis Q	Infant	60	0.48	0.06 ± 0.003	8.0 ± 0.6
C	Toshiba Ultimix	Neonate < 5kg	60	0.46	0.06 ± 0.003	10.4 ± 0.8
Test lab	GE Innova	Low dose	63	0.26	0.04 ± 0.003	9.5 ± 0.6
Cineangiography						
Institution	Manufacturer	Imaging mode ¹	kVp	Air kerma (mGy)	Effective dose per 1000 frames	IQ score ²
A	Philips AlluraXper	Infant < 10lbs	69	4.2	0.57 ± 0.03	11.1 ± 0.3
A	Phillips AlluraClarity	Infant < 10lbs	66	1.3	0.17 ± 0.01	11.0 ± 0.3
B	Siemens Artis Q	Child	76	2.7	0.41 ± 0.02	10.1 ± 0.5
C	Toshiba Ultimix	Neonate < 5kg	63	3.7	0.52 ± 0.03	11.2 ± 0.3
Test lab	GE Innova	Low dose	60	1.8	0.29 ± 0.02	10.6 ± 0.8

¹Imaging mode represents the system-defined mode

²IQ scores represent mean objective scores across the 3 reviewers ± 1SD

Table 3.

Typical institutional imaging parameters

		Fluoroscopy		Cineangiography	
Institution	Vendor	Mag	Frame rate (fps)	Mag	Frame rate (fps)
A	Phillips allura	7"	15	7"	30
A	Phillips clarity	7"	5	7"	7.5
B	Siemens	16cm	5	16cm	7.5
C	Toshiba	7"	5	Use fluoro-save mode	
D	GE	7"	5	7"	7.5

Data provided represent the typical baseline imaging parameters at each institution for neonatal imaging. All institutions vary imaging approaches depending on procedural objectives.