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A multihospital survey of radiation exposure and image quality in pediatric fluoroscopy

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Abstract *Background.* Traditionally, pediatric radiologists have been advocates of fluoroscopy systems that provide diagnostic images at the lowest possible radiation dose to the pediatric patient. Manufacturers of fluoroscopic equipment vary as to their claims of "low radiation" exposures.
Objectives. To obtain comparative data on radiation exposure and image quality from four pediatric hospitals, across variants of fluoroscopic equipment (such as pulsed versus continuous fluoroscopy).
Materials and methods. Images were acquired from phantoms that simulated the size of a 3-year-old child. Phantom results, both stationary and rotating dynamic, were evaluated for radiation exposure and for image resolution of high- and low-contrast objects.
Results. Radiation exposure from the four fluoro units varied widely; the lowest-dose selectable fluoro mode produced exposures varying between 34 and 590 mrads/min among the four fluoro units, and the highest-dose selectable fluoro mode produced 540–2230 mrads/min. The lowest radiation exposures were produced by pulsed fluoro units, and the very lowest radiation exposure was produced by a fluoroscope that had been especially optimized for pediatric imaging. There was only a small variation in image quality among the hospitals for visualization of stationary objects. A wide variability was noted for detection of objects on the moving phantom.
Conclusions. The variability in the number of detected objects was considerably smaller than the variability in radiation exposure. Pulsed fluoroscopy provides improved resolution for moving objects. Optimization of one hospital's fluoroscope especially for pediatric imaging produced the best ratio of image quality to radiation exposure.

Introduction

We have previously described the methodology used to optimize fluoroscopic performance in a newly installed fluoroscope at Oregon Health Sciences University [1]. Herein we present a further description of a survey of fluoroscopic imaging performance carried out at four pediatric hospitals with four different fluoroscopes. We were interested in comparing radiation exposure levels (after hearing claims from various vendors of fluoroscopes that each had the lowest radiation exposures), and we were especially interested in comparing continuous fluoroscopy to pulsed fluoroscopy, with pulsed fluoroscopy being generally available in two different modes, depending on the vendor. The comparison between one manufacturer's continuous fluoroscopy versus that same manufacturer's pulsed fluoroscopy has been presented previously [1]. Some discussion of the two pulsed fluoro modes available from various vendors is in order.

Pulsed fluoroscopy is typically offered in one or the other of two modes: first, in *primary-switched* or *kVp-pulsed* fluoro, the kVp voltage to the X-ray tube anode is turned on and off at the pulse rate, typically 4–15 pulses/s (PPS). Because of the electrical engineering complexities associated with rapidly turning on and off such high voltages at the X-ray tube anode, kVp-pulsed fluoro may produce low kVp X-ray tails (at the rise and fall of each X-ray pulse). These low-energy tails would produce smearing of temporal resolution in the image of moving objects, and because of their very low energy, these tails would then also deliver unnecessarily high exposures to the patient's skin.

The second pulsed fluoroscopy mode is known as *grid-pulsed* fluoro. In grid-pulsed fluoro, the X-ray tube anode is kept continuously energized at the kVp voltage, but the electron beam in the X-ray tube can be sharply turned on or off with a grid (essentially a metal cup) that surrounds the X-ray tube filament. Grid-switching involves only low voltages, which does not therefore have the electrical engineering complexities that are involved in the pulsing of the high-voltage anode kVp circuit. Because grid-pulsing should produce no leading or trailing low-energy tails on the X-ray pulses, the vendors of grid-pulsed fluoroscopy equipment represent their equipment as having both improved temporal resolution and an absence of the objectionable excess radiation dose from X-ray pulse tails.

Materials and methods

We compared radiation dose and phantom image quality at four children's hospitals. Two different phantoms were employed, one stationary and one rotating dynamic, as detailed below. This performance survey is not intended as a comprehensive comparative evaluation of equipment performance from various vendors, and to this end, we have not identified the equipment vendors involved. Rather this performance survey is a simple snapshot of imaging performance among equipment, as was observed in clinical practice at four children's hospitals. The fluoroscopy unit at any hospital can be expected to have a performance that is affected by many parameters, notably age since installation and size of the image intensifier. Except for the fluoroscope at Oregon Health Sciences University (OHSU, identified here as hospital 2), the other three fluoroscopy units were not subjected to any optimization processes prior to our testing. The performance of any fluoroscope can be markedly affected by optimization processes such as we used at OHSU. We simply tested the fluoroscopes at the other three hospitals as we found them, as they were functioning in day-to-day clinical use. We believe that our experiments give an indication, albeit it from a small sample of children's hospitals, of the degree of variability in fluoroscopic equipment performance, as currently used in the practice of pediatric radiology.

One of the authors (PHB) traveled to the four children's hospitals and imaged the stationary U.S. Food and Drug Administration/Center for Devices and Radiological Health (CDRH) fluoroscopy phantom [1], as well as an additional dynamic rotating phantom, on four fluoroscopes from four different equipment vendors. The moving phantom is described below and was used to evaluate the image quality of continuous versus pulsed fluoroscopy for detection of moving objects. One of the fluoro units (hospital 1) had only continuous fluoroscopy (no pulsed fluoro capability); the other three fluoro units all had pulsed fluoro capabilities (one, hospital 2 with grid-pulsed, and hospitals 3 and 4 with kVp-pulsed). Hospital 2 had a fluoroscope that had been especially engineered and optimized for pediatric imaging [1]. We were interested in comparing the radiation dose and visibility of stationary and moving objects on these four various fluoroscopic designs. The methodology used for evaluating image quality with the stationary CDRH phantom has been described previously [1]. We imaged the CDRH phantom at each hospital with 5- and 10-cm-thick Plexiglas phantoms, but for brevity's sake only the results for the 10-cm-thick phantom (simulating a 3-year-old child) will be presented here.

The dynamic moving phantom was a disk rotating at 1 rev/8 s, with a speed at the outer margin of the disk of 2 cm/s (similar to physiological cardiac motion). The moving phantom has a series of various diameter high-contrast wire test objects, oriented radially, placed at the outer circumference of the phantom. Image quality with the moving phantom was assessed by simply counting the number of high-contrast wire objects that could be seen in the fluoroscopic image on the video monitor, using continuous and pulsed fluoroscopic modes.

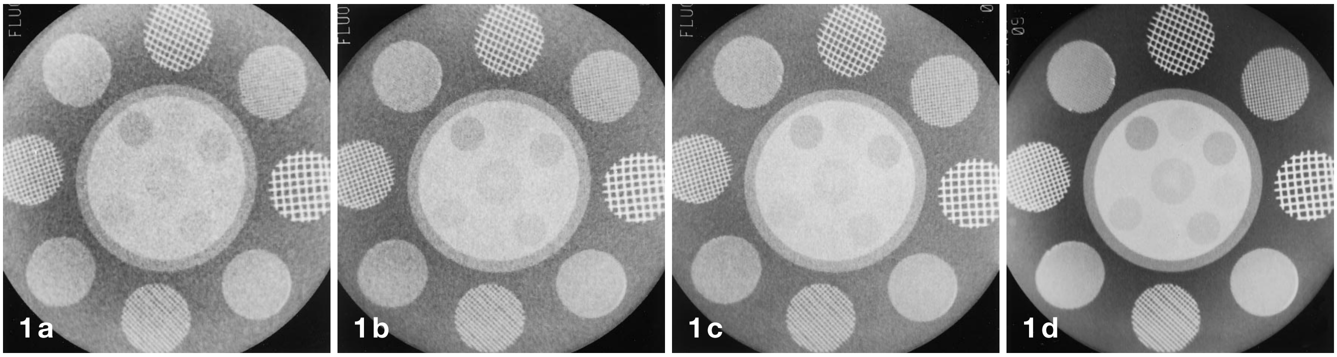
These fluoroscopes varied in image-intensifier sizes, magnification modes, and many other factors that could affect the results that were obtained. As much as possible, we used a magnification mode that produced about a 6-in. field of view, but this was not always precisely the same, and magnification has a very strong influence on detectability of high-contrast objects. Differences between hospitals in the number of high-contrast mesh may not reflect any inherent performance advantage in any one particular fluoroscope – it may be merely a manifestation of more or less image magnification. Moreover, hospitals 1–3 were tested with the image intensifier antiscatter grid-out (our preference for pediatric imaging), whereas hospital 4 was tested with the grid in because the grid was fixed in on the image intensifier at hospital 4. This situation at hospital 4 (grid fixed-in), would be expected to provide an advantage in image quality with a necessarily higher radiation exposure. The geometry of placement of the phantoms and radiation detection chamber was held constant at each hospital [1].

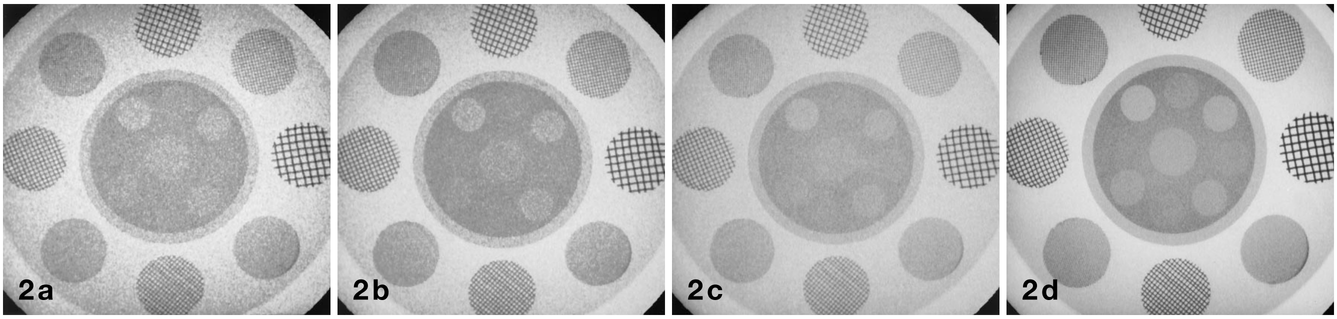
Results

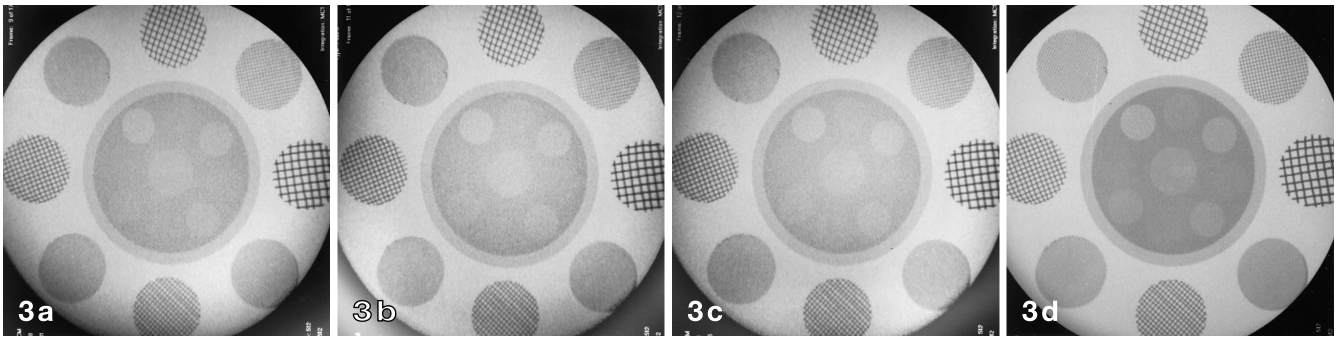
Comparison of the four children's hospitals: stationary phantom

Figures 1–4 show the CDRH stationary phantom results for hospitals 1–4. For brevity's sake, only three of the (sometimes more) available fluoro modes are shown for each hospital, spanning the range from lowest to highest radiation level at each hospital. Table 1, derived from the images in Figs. 1–4, shows a tabular comparison of the imaging results for the stationary CDRH phantom. The lowest radiation exposure that could be selected on each hospital's fluoroscope varied from 34 to 590 mrads/min. The highest radiation mode that could be selected on each fluoroscope produced radiation exposure varying from 540 to 2230 mrads/min. We conclude that there was a wide range of radiation exposure variability among the hospitals.

However, Table 1 (and Figs. 1–4) show that there was only a narrow range of variability in image quality among the hospitals. When the fluoroscope was set to its minimum selectable radiation output (the 1st three data rows in Table 1), the fluoroscopes at the various hospitals visualized between 5 and 7 high-contrast







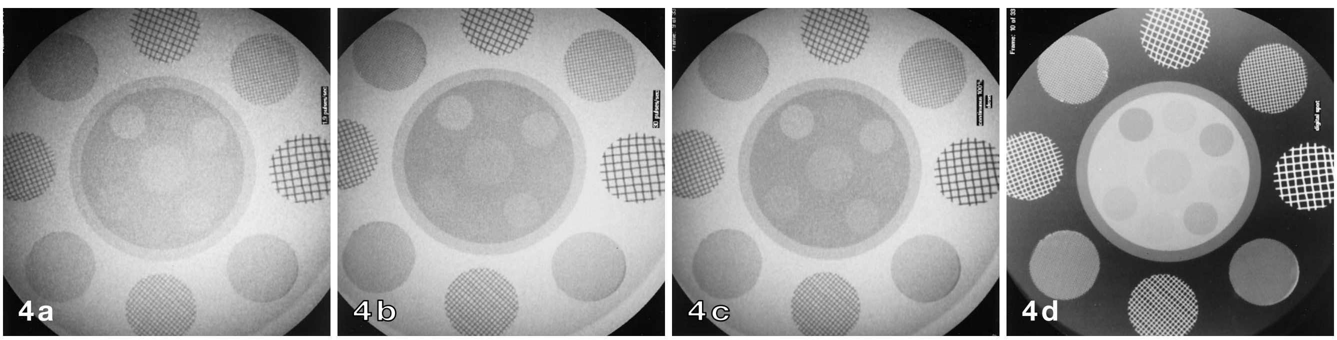


Fig. 1 a–d Hospital 1. Images of the stationary CDRH phantom, fluoro-grab images (**a–c**) (mrad/min). **a** Low-dose continuous (590), **b** medium-dose continuous (1097), **c** full-dose continuous (2230). **d** A digital spot image

Fig. 2 a–d Hospital 2. Images of the stationary CDRH, fluoro-grab images (**a–c**) (mrad/min). **a** Pediatric pulsed low (34), **b** adult pulsed high (231), **c** continuous (541). **d** A digital spot image

Fig. 3 a–d Hospital 3. Images of the stationary CDRH phantom, fluoro-grab images (**a–c**) (mrad/min). **a** 7.5 PPS pulsed fluoro (280), **b** 30 PPS pulsed fluoro (1010), **c** continuous fluoro (1220). **d** A digital spot image

Fig. 4 a–d Hospital 4. Images of the stationary CDRH phantom, fluoro-grab images (**a–c**) (mrad/min). **a** 1.9 PPS pulsed fluoro (390), **b** 30 PPS pulsed fluoro (1870), **c** continuous fluoro (2050). **d** A digital spot image

Table 1 Imaging performance and radiation exposure levels at the four children's hospitals for the stationary CDRH phantom and the dynamic moving phantom

≅ 6-in. field-of-view, 10 cm Plexiglas	Hospital 1	Hospital 2	Hospital 3	Hospital 4
Grid:	Out	Out	Out	Fixed, in
@ *Lowest* fluoroscopic mrad/min	590	34	280	390
No. of *stationary* CDRH phantom high-contrast mesh seen	5	6	7	7
No. of *stationary* CDRH phantom low-contrast holes seen	5	4	5	5
@ ≅ 500 mrad/min fluoroscopic	590	541	550	530
No. of *stationary* CDRH phantom high-contrast mesh seen	5	6	7	7
No. of *stationary* CDRH phantom low-contrast holes seen	5	5	5	5
@ *Highest* fluoroscopic mrad/min	2230	541	1220	2050
No. of *stationary* CDRH phantom high-contrast mesh seen	6	6	7	8
No. of *stationary* CDRH phantom low-contrast holes seen	6	5	5	6
Rotating phantom, no. of objects seen on continuous fluoro	5	6	6	7
Rotating phantom, no. of objects seen on pulsed fluoro	No pulsed	9	9	7
Pulsed: Lowest – highest available fluoro *radiation exposure* (mrad/min)	No pulsed	(34–231)	(280–1010)	(390–1870)
Continuous: Lowest – highest available fluoro *radiation exposure* (mrad/min)	(590–2230)	(322–541)	(1220–1220)	(410–2050)
Digital spot image, no. of *stationary* CDRH phantom high-contrast mesh seen	7	8	8	8
Digital spot image, no. of *stationary* CDRH phantom low-contrast holes seen	7	8	7	8

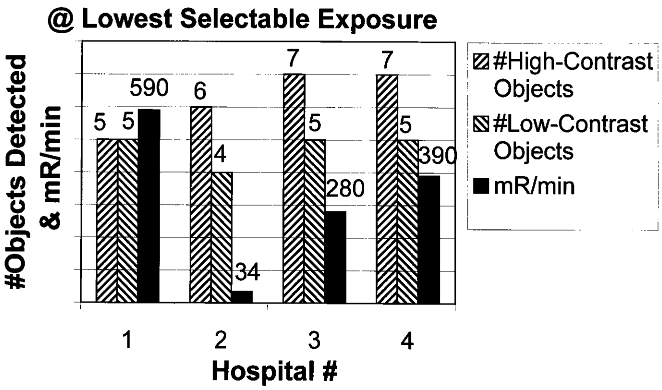


Fig. 5 Number of detected objects and radiation exposure in the stationary 10-cm-thick phantom *at the lowest selectable radiation exposure* at each hospital

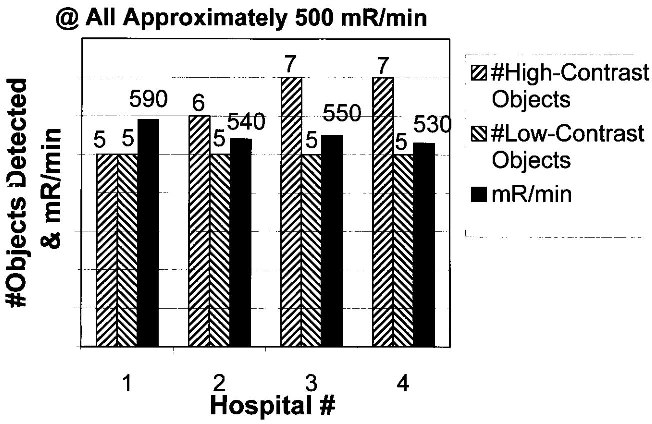
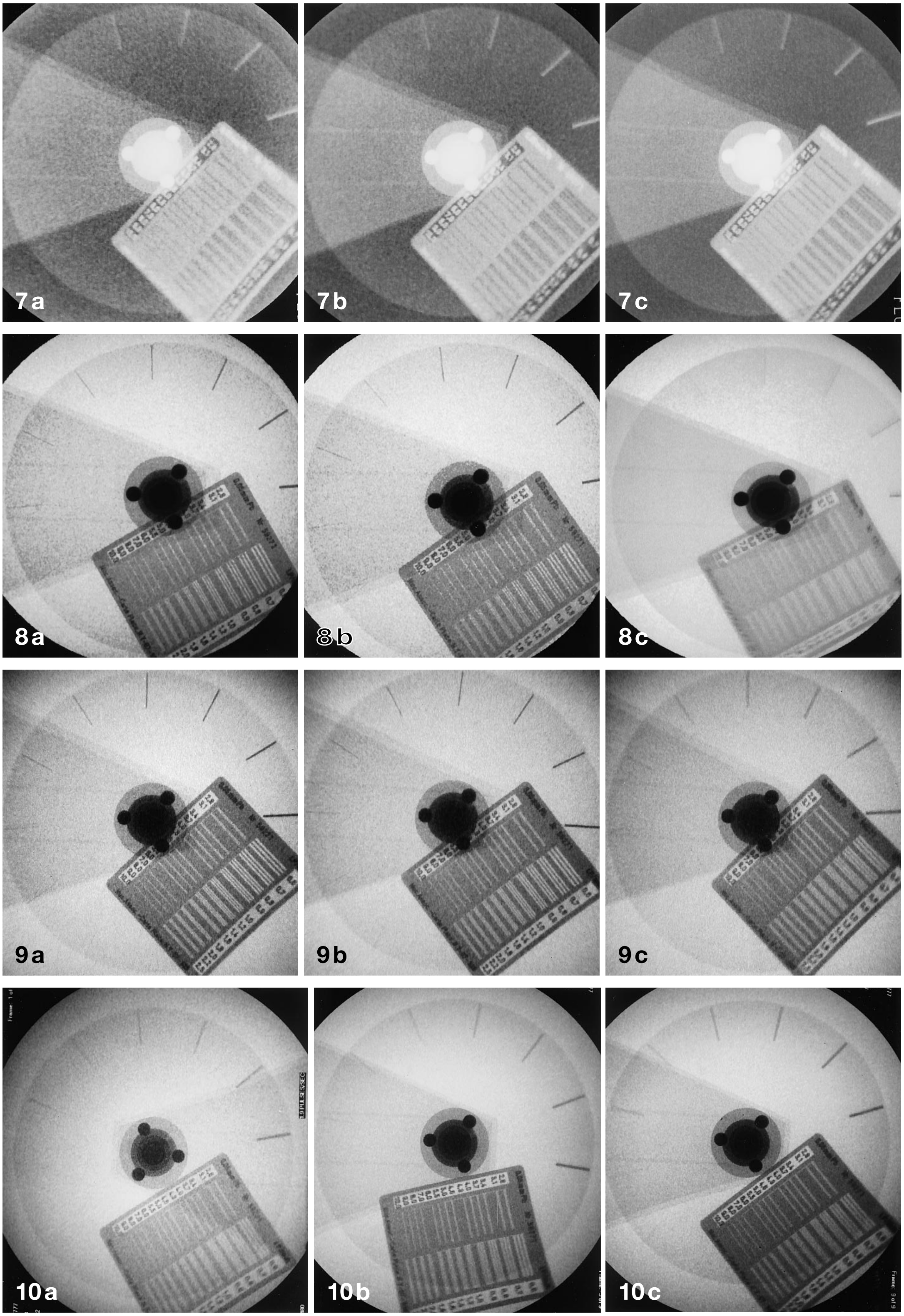


Fig. 6 Number of detected objects and radiation exposure in the stationary phantom at *comparable radiation exposure* (approximately 500 mrad/min) at each hospital

mesh, and between 4 and 5 low-contrast holes. A graphic comparison between the number of objects detected and radiation exposure, *at the lowest selectable exposure level* for each hospital, is shown in Fig. 5. This figure shows that operating with the lowest radiation exposure fluoroscope (34 mrads/min) at hospital 2 did not significantly degrade image quality compared to the other hospitals operating at 10–20 times higher minimum selectable radiation exposure. There was only a very weak correlation between the number of objects detected and the radiation exposure level. It should be kept in mind that the methodology involved here utilized just one person who recorded the number of phantom objects visible on the live fluoroscopic video monitor, and that this methodology has an uncertainty that we estimate at ± 0.5 high-contrast mesh or ± 1 low-contrast holes. It was also not possible to control all variables such as image magnification, image intensifier diameter, video monitor brightness and contrast, room lighting, etc. – all factors that lend imprecision to the number of detected objects. The images are available for inspection in Figs. 1–4, but keep in mind that these images have been through several photographic steps, so they may not completely represent what was visible on the video monitor during the live fluoro (as listed in Table 1).

Since there was such a wide range between the fluoroscopes in terms of their minimum attainable radiation exposure (between 34 and 590 mrads/min), we decided to compare image quality at *comparable radia-*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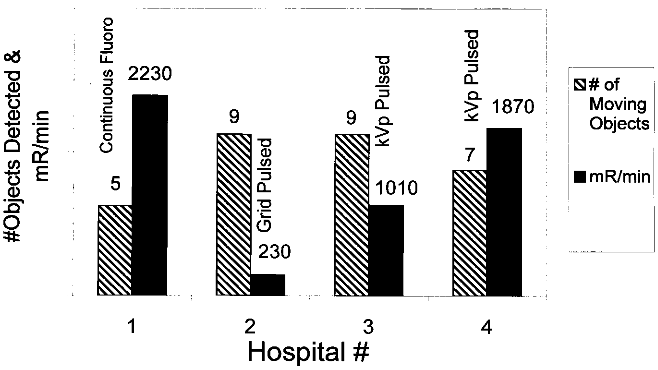

Fig. 11 Number of detected objects and radiation exposure for the *dynamic rotating* phantom at each hospital

tion exposure, for which we selected a fluoroscopic output near 500 mrads/min (an operating level suggested from a previous study of pediatric radiation levels [2]). The 2nd three data rows in Table 1 show that when each fluoroscope was operated near 500 mrads/min, the high-contrast resolution remained the same as at the lowest selectable radiation exposure (range 5–7 mesh detected) and the low-contrast resolution was improved only at hospital 2, where it increased to 5 holes detected. A comparison between the number of objects detected and radiation exposure, at approximately the same 500 mrads/min radiation exposure level for each hospital, is shown in Fig. 6. At comparable radiation exposure levels, the four hospitals showed even less variation in image quality for detection of stationary objects than at their lowest selectable radiation exposure level.

At the 500 mrads/min exposure level, use of the antiscatter grid on the image intensifier at hospital 4 (as compared to hospitals 1–3 where the antiscatter grid was not used) did not convey any advantage in image quality at hospital 4, probably because of the relatively thin 10-cm phantom thickness. Since the grid at hospital 4 was not removable, we could not investigate how much it was increasing the radiation exposure levels, but this is likely to be a component in the relatively higher exposure levels at hospital 4.

◀ **Fig. 7 a–c** Hospital 1. Dynamic phantom images, fluoro-grab images. **a** Low-dose continuous fluoro, **b** medium-dose continuous fluoro, **c** high-dose continuous fluoro

Fig. 8 a–c Hospital 2. Dynamic phantom images, fluoro-grab images. **a** Pediatric pulsed low, **b** adult pulsed high, **c** continuous fluoro

Fig. 9 a–c Hospital 3. Dynamic phantom images, fluoro-grab images. **a** 7.5 PPS pulsed fluoro, **b** 30 PPS pulsed fluoro, **c** continuous fluoro

Fig. 10 a–c Hospital 4. Dynamic phantom images, fluoro-grab images. **a** 1.9 PPS pulsed fluoro, **b** 30 PPS pulsed fluoro, **c** continuous fluoro

Lastly, we compared the image quality *in the highest selectable radiation level* fluoroscopy mode (540–2230 mrads/min) on each fluoroscope, the 3rd three data rows in Table 1. At these higher radiation levels, the four fluoroscopes detected a few more objects than at lower radiation levels, but the variability among the hospitals remained small (range 6–8 high-contrast mesh, 5–6 low-contrast holes), and the image quality at hospital 2 (540 mrads/min) was almost as good as at the other hospitals with significantly higher maximum radiation exposures (1220–2230 mrads/min). Hospital 4 shows a slight image-quality advantage, although at a relatively high 2050 mrads/min, possibly due to the use of the antiscatter grid at this hospital.

Comparison of digital spot images, stationary phantom

Because there is occasionally a need for high-detail images in a pediatric fluoroscopic examination, we also compared the results of digital spot images from the four hospitals. The fluoroscopic images shown in this work for pulsed or continuous fluoroscopy are low-radiation fluoroscopic images of a single fluoroscopy video frame (fluoro-grab). A digital spot image, on the other hand, is more like a radiographic film/screen quality digital image, representing more radiation exposure than a fluoro-grab image, with significantly improved image quality compared to a fluoro-grab image. The digital spot images are shown in Figs. 1–4. The bottom rows of Table 1 (representing the digital spot data from Figs. 1–4) show that once again there was only slight variation among the hospitals in terms of digital spot image quality; all the hospitals detected 7–8 high-contrast mesh and 7–8 low-contrast holes. The use of the antiscatter grid on the image intensifier at hospital 4 did not convey any definitive advantage in digital spot image quality.

Moving phantom, comparison of the four children's hospitals

Figures 7–10 show the dynamic moving phantom results for hospitals 1–4. The middle of Table 1, derived from the images in Figs. 7–10, shows a tabular comparison. A graphical comparison between the number of objects detected on the moving dynamic phantom and radiation exposure at each hospital is shown in Fig. 11. In contrast to the small variation between the four hospitals in image quality for stationary objects, we found a striking amount of variability in image quality (from 5 to 9 detected moving objects) among the hospitals with the rotating phantom. Because of the rotating motion of the phantom, the fluoroscopic image of the wire objects is expected to be blurred in continuous fluoroscopy, whereas the wires should be more visible with the stopmotion imaging produced by pulsed fluoroscopy. This was indeed the case, as shown in Fig. 11. Hospital 1, which had only continuous fluoroscopy, could resolve only five moving wire objects, whereas hospitals 2–4 resolved from 7–9 moving wire objects using pulsed fluoroscopy. Furthermore, note from Fig. 11 that the improved temporal resolution of the pulsed fluoroscopy hospitals was achieved at lower radiation exposures than in the continuous fluoroscopy at hospital 1.

One of our objectives was to see if grid-pulsed was an improvement, in terms of *image quality,* over kVp-pulsed fluoroscopy. Hospitals 2 and 3 both visualized the same high number of nine moving objects, even though the pulsed fluoroscopy design between these two hospitals is fundamentally different. Hospital 2 represents grid-pulsed fluoroscopy, whereas hospital 3 represents kVp-pulsed fluoroscopy. The pulsed fluoroscopy at hospital 4, also kVp-pulsed fluoroscopy, had slightly less dynamic phantom resolution than at the other two pulsed fluoroscopy hospitals. Overall, these data fail to demonstrate any image quality superiority of grid-pulsed versus kVp-pulsed fluoroscopy.

Comparing the *radiation exposure levels* of grid-pulsed versus kVp-pulsed shows that a radiation exposure was obtained at grid-pulsed hospital 2 (230 mrads/min), as compared to kVp-pulsed hospitals 3 and 4 (1010 and 1870 mrads/min). The lower pulsed fluoro exposure at hospital 2 may be at least partially due to the advantages of grid-pulsed fluoroscopy. However, this is not a conclusive demonstration of any superiority of grid-pulsed versus kVp-pulsed, because the grid-pulsed hospital 2 also had numerous other optimizations of the fluoroscope for pediatric imaging [1].

However, the experimental result remains that hospital 2 (pediatric optimized grid-pulsed) produced dynamic phantom resolution that was comparable to or better than hospitals 3 and 4 (unoptimized kVp-pulsed), but hospital 2 required far less radiation (at least a factor of × 5 less) to produce this image-quality performance.

Discussion

The major conclusions from this study were:

1. A survey of pediatric fluoroscopic imaging performance at four children's hospitals showed a very wide range of radiation exposure, whereas there was only a small variation in image quality for detection of *stationary* objects.
2. The fluoroscope at hospital 2 that had been optimized for pediatric fluoroscopy produced markedly less radiation exposure and image quality for stationary objects that was practically comparable to that at the other three hospitals (with fluoroscopes that were not especially optimized for pediatric imaging).
3. The greatest variation in imaging quality among the four hospitals involved image quality for *moving* objects.
4. The strongest determinant of visualization of *moving* objects was the ability to perform pulsed fluoroscopy.
5. The optimized pediatric fluoroscope at OHSU produced comparable image quality for moving objects using grid-pulsed fluoroscopy, at considerably less radiation exposure, than in the unoptimized fluoroscopes with kVp-pulsed fluoroscopy.

As noted in the Materials and methods section, the data reported here are not intended to be any sort of comprehensive comparison between the fluoroscopic products from various vendors. Rather this is intended as a simple snapshot of the performance of pediatric fluoroscopes as they are being used in pediatric hospitals. There may be weaknesses in the methodology used here, of defining image quality based on just one person's interpretation of image quality on the video monitor. However, the major conclusions appear sound, since for instance the variation in lowest available radiation exposure among the hospitals showed irrefutably marked variation (almost a factor of 20), whereas the image quality for stationary objects showed little if any variation (especially given the intraobserver uncertainty, image magnification effects, etc.). Likewise, the major improvement in visibility of objects on the dynamic phantom using pulsed fluoroscopy compared to continuous fluoroscopy (almost a factor of two more moving objects detected) far exceeded any conceivable intraobserver variation levels in the counting of visualized objects.

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References

1. Brown PH, Thomas RD, Silberberg PJ, et al (1999) Optimization of a fluoroscope to reduce radiation exposure in pediatric imaging. Pediatr Radiol (in press)
2. Hernandez RJ, Goodsitt MM (1996) Reduction of radiation dose in pediatric patients using pulsed fluoroscopy. AJR 167: 1247–1253