Pediatr Radiol (2006) 36 (Suppl 2): 216–220
DOI 10.1007/s00247-006-0216-0

ALARA

Dick Stueve

Management of pediatric radiation dose using Philips fluoroscopy systems DoseWise: perfect image, perfect sense

Published online: 22 July 2006

Abstract Although image quality (IQ) is the ultimate goal for accurate diagnosis and treatment, minimizing radiation dose is equally important. This is especially true when pediatric patients are examined, because their sensitivity to radiation-induced cancer is two to three times greater than that of adults. DoseWise is an ALARA-based philosophy within Philips Medical Systems that is active at every level of product design. It encompasses a set of techniques, programs and practices that ensures optimal IQ while protecting people in the X-ray environments. DoseWise methods include management of the X-ray beam, less radiation-on time and more dose information for the operator. Smart beam management provides automatic customization of the X-ray beam spectrum, shape, and pulse frequency. The Philips-patented grid-controlled fluoroscopy (GCF) provides grid switching of the X-ray beam in the X-ray tube instead of the traditional generator switching method. In the examination of pediatric patients, DoseWise technology has been scientifically documented to reduce radiation dose to <10% of the dose of traditional continuous fluoroscopy systems. The result is improved IQ at a significantly lower effective dose, which contributes to the safety of patients and staff.

Keywords Pediatric dose management · Fluoroscopic equipment · Technical advances

Introduction

This paper discusses the ALARA (as low as reasonably achievable) methods used by Philips Medical Systems in the manufacturing of radiographic equipment systems designed to ensure optimal image quality (IQ) while protecting people in the radiographic environment. The increased IQ and dose-limiting solutions incorporated into Philips' DoseWise methodology will be presented. The smart beam management, less radiation-on time and more awareness solutions, active at every level of Philips product design, are addressed, as are the associated equipment components, techniques, and practices used to provide optimal IQ at the lowest dose.

Although IQ is the ultimate goal for accurate diagnosis and treatment, minimizing radiation dose is of equal importance. This is above all true for pediatric patients, who are ten times more sensitive to radiation exposure and the associated cancers [1–3].

Additionally, pediatric patients with complex congenital heart and/or vascular defects may have as many as eight to ten X-ray-monitored interventions during their lifetime [4]. Therefore, the design of fluoroscopy equipment systems and how pediatric examinations are performed will determine how well the ALARA principle is met.

DoseWise

Philips DoseWise is a set of techniques, programs and practices that ensures optimal IQ while protecting people in the X-ray environments [5–8]. It is an ALARA-based philosophy that drives the development of innovative strategies in dose management. There are opportunities to optimize IQ throughout the entire digital detection imaging chain *independent of dose*. Moreover, each of these elements interacts with the others. Consequently, Philips views each fluoroscopy system as a whole and considers how each component affects the rest. To ensure optimal interaction, Philips developed its Eleva and Allura programming. This unique programming is an examination–patient-related automatic parameter-setting control. It includes exposure and fluoroscopy settings to regulate dose levels, parameters for pre- and post-image processing, system geometry settings and beam limitation settings. With minimal user interaction, all the parameters for every type of examination, view and acquisition are optimized for

D. Stueve (✉)
Philips Medical Systems North America,
22100 Bothell-Everett Highway,
Bothell, WA 98021-8431, USA
e-mail: Dick.Stueve@philips.com
Tel.: +1-425-4828567
Fax: +1-425-4828835

all patient types, from newborn infants to large adults. DoseWise processes provide powerful solutions in the following areas:

– Smart beam management
– Less radiation-on time
– More dose awareness

Smart beam management

DoseWise technologies modify the energy spectrum, shape and frequency of the X-ray beam. These real-time modifications allow the beam to semiautomatically adapt to each examination. Smart beam management includes customizing the beam in terms of its spectrum, shape and pulse frequency. It enables the user to modify the beam according to the size of the patient, type of examination and area being examined. The foundation of the smart beam technology is the EPX-based management of preprogrammed examinations common to Philips Eleva fluoroscopy and Allura cardiac and vascular imaging systems. The available examination- and patient-type EPX program selections automatically provide the correct combination of radiographic exposure factors, focal spot size, spectral filtration, fluoroscopy type, fluoroscopy dose levels, fluoroscopic and radiographic exposure rates required to provide the best IQ with minimum radiation.

Radiographic exposure factors

Special pediatric settings are available with all Philips radiographic imaging systems. These programs provide special pediatric exposure curves for grid-controlled fluoroscopy (GCF) and continuous fluoroscopy (Fig. 1). These curves are designed to maintain a voltage level of about 70 kV, even for very small patients. Additionally, an intelligent exposure control (IQX) is designed to rapidly regulate digital radiographic exposures when children are imaged. The available range of IQX exposure curves provided with the EasyDiagnost Eleva, MultiDiagnost Eleva and OmniDiagnost Eleva systems give optimal characteristics for both pediatric and adult examinations. If required, custom exposure and fluoroscopy settings for specific applications can be obtained via adjustments within the incorporated EVA tool.

Spectral beam filters

The spectrum of conventional X-ray tubes contains a significant amount of soft radiation, i.e., X-rays that enter the patient's skin but do not have enough energy to reach the image detector. The combination of powerful Philips X-ray tubes and SpectraBeam filters effectively removes unwanted soft radiation from the beam, resulting in significantly less dose to the patient and X-ray personnel [9] without compromising IQ (Fig. 2). Depending on the

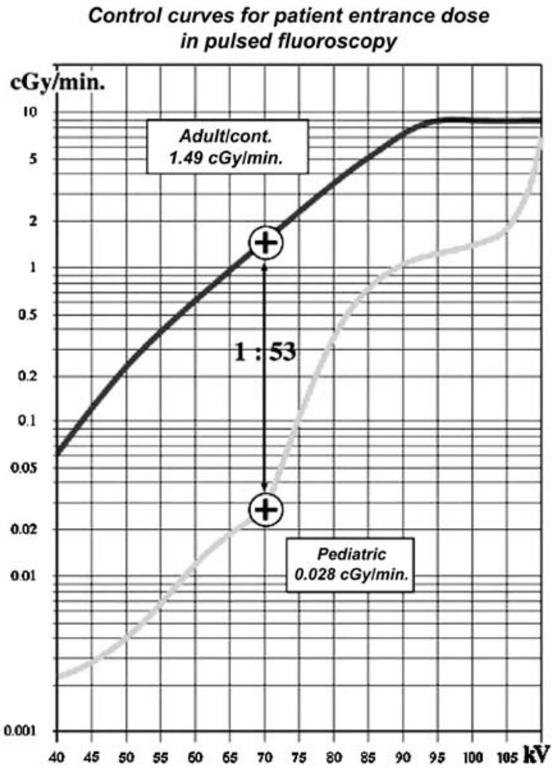

Fig. 1 Philips GCF in-pulse control technology allows the development of special pediatric dose curves, which provide pulse durations of ≤10 ms and low-dose settings. At the indicated points in the graph, the patient dose produced by the pediatric curve is approximately 50 times less than that of the adult continuous fluoroscopy curve

equipment type, selected examination and patient size, different thicknesses of copper (Cu) spectral filters located in the X-ray tube collimator, are automatically inserted into the beam. The selection of the soft X-ray-absorbing spectral filters includes Cu absorbers that are 0.1-mm, 0.2-mm, 0.4-mm and 0.9-mm thick and are used in conjunction with a 1.0-mm thick aluminum (Al) filter. SpectraBeam filters available with Philips Eleva fluoroscopy and radiographic systems are 0.1- and 0.2-mm Cu filters, while Philips Allura cardiac and vascular equipment has 0.1-, 0.4- and 0.9-mm Cu filters. Typically, a 0.1-mm Cu filter reduces exposure of the patient by approximately 50%, while a 2-mm Cu filter reduces the dose by roughly 70%.

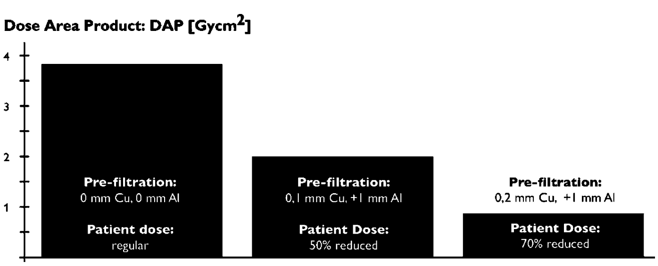

Fig. 2 Spectral beam filters absorb soft radiations that increase exposure of the patient's skin. A 0.1-mm Cu + 1-mm Al filter reduces patient exposure by 50%, while a 0.2-mm Cu + 1-mm Al filter reduces patient dose by 70%

The 0.1- and 0.4-mm Cu filters are commonly used during complex adult interventional procedures, where long fluoroscopy exposure times are common. Use of a 0.9-mm thick Cu filter is preferred during examinations of newborns and small pediatric patients and during electrophysiology (EP) examinations, where significantly reduced patient entrance exposures might be warranted. In cardiac and vascular procedures, the 0.1- and 0.4-mm thick Cu filters provide maximum fluoroscopy exposure rates of approximately 10.0 R/min and 5.0 R/min, respectively. The 0.9-mm Cu filter provides a maximum fluoroscopy exposure rate of 1.5 R/min. Use of specific spectral filters is dependant on the type of examination being performed. In standard adult fluoroscopy, a maximum filtration of 0.2-mm Cu achieves diagnostic IQ. In standard pediatric radiology, a 0.1-mm Cu filter provides the best relationship between diagnostically relevant images and the lowest possible dose.

Customizing the beam shape

The collimators used with Philips imaging systems are designed with three successive steps to manipulate the shape of the X-ray beam, thereby avoiding radiating adjacent tissue. A lead (Pb) iris-shape shutter positioned next to the output port of the X-ray tube clearly defines the edge of the beam. Two square Pb shutters, one positioned above the other, further adapt the beam shape. Finally, thin Cu wedge filters within the collimator can be positioned by the operator to complete the beam-shaping process, creating a custom beam shape for the examination. Additionally, to further reduce unnecessary exposure of the patient, the beam-limiting shutters and wedge filters can be positioned on a displayed last-image-hold (LIH) image without the use of extra radiation.

Adaptive measuring field (AMF)

Fluoroscopic image brightness fluctuates whenever variations in anatomical structures produce varying light levels. Generally, this occurs when the system is panned across the patient's anatomy. Image brightness is also affected whenever the beam-collimating shutters are closed too tightly into the field-of-view. When this occurs an automatic exposure control (AEC) system, (designed to maintain a consistent image brightness level), responds by increasing the X-ray exposure to the image receptor - and the patient. The result is an over-exposed, low-quality image. Philips Eleva imaging systems employ a centrally positioned measuring field that monitors a 40–60% central area of the fluoroscopic image. Real-time electronic communications between the image receptor and the X-ray generator provide instantaneous responses to the variations in image brightness caused by the anatomical variations and/or system panning described previously. Philips AMF technology ensures that there is never an over-exposed image, even when the shutters are almost closed. The AMF technology automatically recognizes the position of the shutters and uses the remaining area of the measuring field to monitor image brightness and, by doing so, continues to provide correctly exposed images (Fig. 3).

AEC lock-in

AEC lock-in, a feature of grid-controlled fluoroscopy, allows the operator to maintain good IQ during procedures such as voiding cystourethrograms (VUG), where the bladder is filled with a dense contrast agent, or when opaque objects, such as lead gloves, enter the field-of-view. This selectable feature freezes the function of the AEC system and maintains optimal IQ by eliminating the blooming effect, which produces low patient doses throughout the examination.

X-ray tubes

Table 1 lists the available Philips equipment systems and associated X-ray tubes with application to pediatric examinations.

Less radiation-on time

With a wide range of automatic parameter settings, which cover the complete range from large adults to small infants, Philips DoseWise uses a foundation of exposure data and automatic equipment functions to make sure that every exposure results in a diagnostically relevant image. This "first time right" philosophy virtually eliminates the need to retake images. Furthermore, the wide dynamic range of the imaging chain and the inherent digital image processing techniques consistently provides high-quality diagnostic images. IQX, Philips unique in-pulse control technology for radiographic examinations, monitors exposures in real time and adjusts settings within the exposure itself. When initial settings cause the incorrect exposure, the IQX adjusts the radiographic factors within the first millisecond of exposure, eliminating unnecessary exposure of the patient.

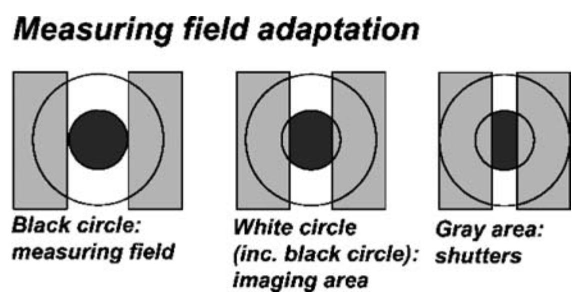

Fig. 3 Philips AMF technology automatically monitors shutter positions to prevent over-exposure to the patient when very small fields-of-view are used

Table 1 Philips available equipment systems and associated X-ray tubes with application to pediatric examinations

Equipment type	Tube type	Anode angle (°)	Small focal spot (mm)	Rating (kW)	Large focal spot (mm)	Rating (kW)
EasyDiagnost Eleva	SRM2250 ROT 500GS	15	0.5	26	1.0	60
	SRO 2250 ROT 360	15	0.6	30	1.0	60
	SRO 33/199 ROT 360	13	0.6	39	1.2	105
MultiDiagnost Eleva	SRM 0608 ROT-GS 505	12	0.6	44	0.8	54
	SRO 33/199 ROT 360	13	0.6	39	1.2	105
Allura Xper FD10	MRC 200 0508 ROT 1001	9	0.5	45	0.8	85
	MRC 200 0508 ROT 1003	9	0.5	45	0.8	85
	MRC 200 0508 ROT-GS 1003	9	0.5	45	0.8	85
Allura Xper FD20	MRC 200 0407 ROT-GS 1004	11	0.4	25	0.7	58
Integris Allura 12/15	MRC 200 0310 ROT-GS 1004	11	0.3	16	1.0	80
	MRM 0410 ROT-GS 1004	11	0.3	29	1.0	100

In-pulse control of the radiographic exposure factors ensures that the beam correctly penetrates the patient to provide optimal exposure and fluoroscopy IQ. This technology allows recorded images that are correct the first time, eliminating the need for repeat exposures. During fluoroscopy, pulsing the beam reduces the radiation-on time. Low pulse frequencies provide significant dose reductions while ensuring diagnostically relevant images. In conventional pulsed fluoroscopy, the intensity of the beam is regulated *after each pulse*, with successive adjustments of four or more pulses required to optimize the beam. In comparison, Philips pulsed fluoroscopy and grid controlled fluoroscopy (GCF) is regulated by a highly advanced in-pulse control circuit that optimizes each pulse independently. Immediately, within the first pulse, the beam's penetration is optimized to provide the relevant diagnostic information (Fig. 4). In-pulse control is active for fluoroscopy and radiographic exposures. For fluoroscopy, GCF is used. For radiographic exposures, IQX is applied. Grid-controlled pulse rates of 7.5 pulses per second, 3.75 pulses per second and 1 pulse per second are available. Philips' exclusive in-pulse control reduces doses by:

- Eliminating over-exposure or under-exposure in every pulse
- Providing immediate diagnostic information with the first pulse

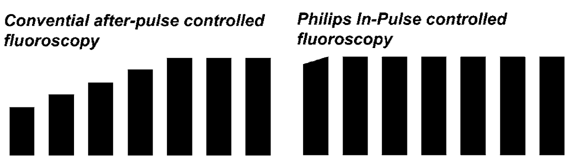

Fig. 4 In conventional pulsed fluoroscopy, four or more pulses are required to optimize the X-ray beam. In comparison, the Philips "in-pulse control" circuit optimizes each pulse independently. Therefore, immediately, within the first pulse, the beam is optimized to provide the relevant diagnostic information

- Avoiding image "blooming" effect common to rapidly changing conditions
- Allowing the use of very low fluoroscopic pulse frequencies
- Providing the continuous selection of different pulse frequencies
- Setting radiographic factors (kV, mA, time) without prior fluoroscopy
- Optimizing exposure factors in real time, thus ensuring constant IQ
- Eliminating excessive exposure times and motion blur

Grid-controlled fluoroscopy

GCF extends the in-pulse control concept with specially designed pediatric fluoroscopy curves and short (≤10 ms) pulse widths [10]. Additionally, Philips GCF utilizes "grid switched" X-ray tubes to create virtually instant pulse rise and fall times [11] (Fig. 5). The "square pulses" provided by GCF are combined with Philips in-pulse control, so the tube voltage (kV), tube current (mA) and pulse width (ms) are optimized for each individual pulse, eliminating exposures that are too short or too long. The instantaneous responses provided by these exceptional features avoid the blooming effect and optimize the radiation dose for each pulse. Radiation surveys have found that continuous fluoroscopy, compared to GCF fluoroscopy, produces

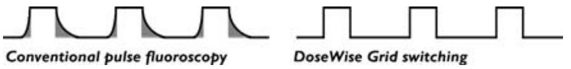

Fig. 5 The X-ray pulses common to conventional, primary (generator)-pulsed imaging systems include a ramp at the beginning of each pulse and a trail at the end of each pulse. The result is increased patient exposure and images with increased motion blur. In comparison, Philips DoseWise grid-switching technology pulses the beam within the X-ray tube, which produces square pulses without the conventional ramps and trails. The benefit of the DoseWise grid-switching technology is significantly less soft radiation and reduced motion blur

about 80–90% more radiation to patients and provides images with excessive motion blur.

GCF contributes to dose reductions by:

- Eliminating ramps and trails
- Enabling immediate pulse optimization
- Utilizing specially designed pediatric fluoroscopy curves

Two studies have been published on the performance of GCF [12, 13]. The first compared four fluoroscopes, a continuous fluoroscopy imaging system, two pulsed fluoroscopy units with primary switch kVp, and one GCF fluoroscopy unit. The results indicated that the grid-pulsed fluoroscopy system produced factors of 10 to 17 times less patient exposure than the other three units, without a loss of IQ. The second study compared the reduction of radiation exposure of a GCF system to that of a continuous fluoroscopy system using piglets to simulate newborn to 6 months, 2- to 3-year-old, and 10-year-old children during cystourethographic examinations. The pulsed fluoroscopy system reduced radiation exposure by a factor of 4.6–7.5 compared to the continuous fluoroscopy system, without a significant loss of IQ.

The ability to display and save last-image-hold images is a technique used to eliminate unnecessary exposure. Philips has improved the typical last-image-hold process by making it possible to record fluoroscopy images at a moment's notice, thus providing the opportunity to replace high-dose radiographic exposures with dynamic fluoroscopy images. While fluoroscopic IQ is usually lower than that of radiographic exposures, its quality is often sufficient to provide diagnostically relevant image information at a significantly reduced patient dose.

More awareness

The DoseWise philosophy has driven the development of simple, easy to interpret dose displays and reporting. Consequently, the user is aware of real-time dose levels and is able to monitor and maintain control of the radiation environment. The Philips fluoroscopy control panel displays clear, immediate information to help the physician decide on the most favorable balance between diagnostic IQ and radiation exposure. Currently, air kerma dose levels are calculated by the equipment system, while the accumulated dose area product (DAP) levels are monitored with a meter located within the X-ray tube collimator. These values are displayed on the physician monitor. Looking to the future, Philips engineers are investigating better methods to provide a patient entrance dose limit display dedicated to the requirements of the intervention laboratory. The prototype system is programmed to alert the physician whenever exposure to multiple predefined patient body zones approach a level of deterministic damage. This technology allows the physician to give full attention to the demanding requirements of the interventional procedure, while the X-ray system monitors radiation exposure to the patient.

Conclusion

In the examination of pediatric patients, Philips' DoseWise technology has been scientifically documented to reduce radiation dose to <10% of the dose of traditional continuous fluoroscopy systems, while always maintaining acceptable IQ. The result of this Philips exclusive technology is improved IQ at a significantly lower effective dose to patients and staff. The benefits of Philips' DoseWise technology feature: grid-pulsed fluoroscopy; pulsed radiographic exposure rates of 7.5 pulses per second, 3.75 pulses per second and 1 pulse per second; AEC lock-in that eliminates increased exposures when dense objects enter the field-of-view; dynamic adaptive AEC measuring fields that automatically respond to the position of the beam-limiting shutters; dynamic spontaneous fluoro grabbing capability that replaces the need for higher-dose radiographic exposures, and clear real-time dose information. All these features allow operators to find the optimal balance between IQ and dose.

References

1. Lu ZF, Nickoloff FL, Rugal-Shapiro CB, et al (2005) New automated fluoroscopic system for pediatric applications. J Appl Clin Med Phys 6:88–105
2. Brown PH, Thomas RD, Silberberg PJ, et al (2000) Optimization of a fluoroscope to reduce radiation exposure in pediatric imaging. Pediatr Radiol 30:229–235
3. den Boer A, de Feyter PJ, Hummell WA, et al (1994) Reduction of radiation exposure while maintaining high-quality fluoroscopic images during interventional cardiology using novel x-ray tube technology with extra beam filtering. Circulation 89:2710–2714
4. Brenner DJ, Elliston CD, Hall EJ, et al (2001) Estimated risks of radiation-induced fatal cancer from pediatric CT. AJR 176:289–296
5. Philips Medical Systems (2002) DoseWise perfect image. Perfect sense. Cardiovascular X-ray (4522 982 88541). Philips Medical Systems Nederland BV
6. Philips Medical Systems (2002) DoseWise perfect image. Perfect sense. Universal RF (4522 982 885710). Philips Medical Systems Nederland BV
7. Philips Medical Systems (2004) DoseWise perfect image. Perfect sense. Inside Philips Fluoroscopy (4522 981 94531). Philips Medical Systems Nederland BV
8. Philips Medical Systems (2004) DoseWise perfect image. Perfect sense. Inside Philips Cardio/Vascular X-ray (4522 981 94541). Philips Medical Systems Nederland BV
9. Shrimpton PC, Jones DG, Wall BF (1988) The influence of tube filtration and potential on patient dose during x-ray examinations. Phys Med Biol 33:1205–1212
10. Hahn H, Faber D, Allmendinger H, et al (1997) Grid-controlled fluoroscopy in paediatric fluoroscopy. MedicaMundi 41:3–6
11. Herrmann K, Helmberger T, Braunschweig R, et al (1995) Grid-controlled fluoroscopy. Philips Medical Systems, Site Report Grosshadren Clinic, University of Munich
12. Brown PH, Silberberg PJ, Thomas RD, et al (2000) A multihospital survey of radiation exposure and image quality in pediatric fluoroscopy. Pediatr Radiol 30:236–242
13. Ward VL, Barnewolt CE, Strauss KJ, et al (2006) Radiation exposure reduction during voiding cystourethrography in a pediatric porcine model of vesicoureteral reflux. Radiology 238:96–106