

Barry Belanger · John Boudry

Management of pediatric radiation dose using GE fluoroscopic equipment

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Abstract In this article, we present GE Healthcare's design philosophy and implementation of X-ray imaging systems with dose management for pediatric patients, as embodied in its current radiography and fluoroscopy and interventional cardiovascular X-ray product offerings. First, we present a basic framework of image quality and dose in the context of a cost–benefit trade-off, with the development of the concept of imaging dose efficiency. A set of key metrics of image quality and dose efficiency is presented, including X-ray source efficiency, detector quantum efficiency (DQE), detector dynamic range, and temporal response, with an explanation of the clinical relevance of each. Second, we present design methods for automatically selecting optimal X-ray technique parameters (kVp, mA, pulse width, and spectral filtration) in real time for various clinical applications. These methods are based on an optimization scheme where patient skin dose is minimized for a target desired image contrast-to-noise ratio. Operator display of skin dose and Dose-Area Product (DAP) is covered, as well. Third, system controls and predefined protocols available to the operator are explained in the context of dose management and the need to meet varying clinical procedure imaging demands. For example, fluoroscopic dose rate is adjustable over a range of 20:1 to adapt to different procedure requirements. Fourth, we discuss the impact of image processing techniques upon dose minimization. In particular, two such techniques, dynamic range compression through adaptive multiband spectral filtering and fluoroscopic noise reduction, are explored in some detail. Fifth, we review a list of system dose-reduction features, including automatic spectral fil-

tration, virtual collimation, variable-rate pulsed fluoroscopic, grid and no-grid techniques, and fluoroscopic loop replay with store. In addition, we describe a new feature that automatically minimizes the patient-to-detector distance, along with an estimate of its dose reduction potential. Finally, two recently developed imaging techniques and their potential effect on dose utilization are discussed. Specifically, we discuss the dose benefits of rotational angiography and low frame rate imaging with advanced image processing in lieu of higher-dose digital subtraction.

Keywords Pediatric dose management · Fluoroscopic equipment · Technical advances

Introduction

Despite the emergence of powerful imaging modalities that do not use ionizing radiation, fluoroscopic X-ray systems continue to play a significant role in medical imaging, particularly for interventional procedures, where real-time imaging is very important. For pediatric patients, the consideration of lifetime radiation risk versus procedural benefit to the patient remains a fundamental consideration for the clinician. For a manufacturer of medical X-ray imaging equipment, it is critically important to exploit advances in X-ray component technologies, image processing, system design and advanced imaging techniques to provide the clinician with the appropriate imaging tools and controls to effectively perform procedures at the lowest possible total X-ray dose. In order to achieve this goal, it is necessary for the manufacturer to understand both the breadth of the desired set of procedures and enough about the objectives of each one to provide the desired imaging capabilities. This, in turn, requires considerable flexibility in the system design along with embedded procedure knowledge in the form of predefined procedure protocols. This article expands upon GE Healthcare's approach to designing X-ray systems for pediatric applications as embodied in two of its current product lines, the Precision 500 D for radiography and fluoroscopy procedures, and the

B. Belanger (✉) · J. Boudry
GE Healthcare Technologies,
9900 Innovation Drive, RP-2124,
Wauwatosa, WI 53226, USA
e-mail: Barry.Belanger@med.ge.com
Tel.: +1-262-3127192
Fax: +1-262-3127266

Innova Digital Flat Panel systems for interventional cardiology and radiology.

Discussion

Basic concepts of image quality and dose

Dose and image quality are bound together in the cost-benefit proposition of medical imaging using ionizing radiation to diagnose and treat patients; therefore, the two should be discussed together. Adherence to the ALARA principle requires judgments on the part of the clinician and the manufacturer. The clinician must judge the level of image quality required for diagnosis and/or therapy in a given procedure and the manufacturer must make technical judgments about what defines “optimal” image quality and the levels of radiation dose required to reach the clinical objectives. GE’s philosophy in this regard can be summarized as follows:

- Maximize imaging dose efficiency: provide the best clinical image quality for any dose level the clinician chooses to use, tailored to intended applications.
- Provide a range of dose/image quality selections to the clinician to fit application needs and preferences.
- Provide dose readout/feedback to the clinician for awareness and decision-making.
- Automate the process as much as possible.

Although dose is well-defined and relatively easy to measure or estimate, image quality is a multidimensional entity judged by the clinician in performing critical visualization tasks. Lacking a complete understanding of the human visual system and higher-level visual brain functions, we must rely on other quantitative methods to characterize image quality, and try to do so in a manner that best correlates with clinicians’ perception. The classical dimensions of image quality include contrast, gray scale, noise, spatial resolution, temporal resolution, low contrast detectability, modulation transfer function, and various distortions. For the purposes of this article, however, we propose a simpler, higher-level list of imaging performance characteristics that are appropriate for modern digital imaging systems, including those with flat-panel detectors:

- X-ray source efficiency
- Detective quantum efficiency as a function of dose: $DQE(f, D)$
- Dynamic range
- Temporal resolution

X-ray source efficiency X-ray source efficiency describes the capability of the generator, X-ray tube, spectral filtration and collimator to produce a dose-efficient (hardened) beam at the required beam energy and of adequate flux in sufficiently short exposure times to achieve clinical imaging objectives with minimal patient skin exposure.

Detective quantum efficiency Detective quantum efficiency [1, 2] is a measure of the information transfer efficiency of a detector. A DQE of unity describes a perfect detector: no information is lost. It is defined as a function of spatial frequency and dose, because we know that the information transfer efficiency of X-ray detectors varies both with the spatial frequency of the incoming information (the X-ray distribution impinging on the detector) and the dose level. Simply put, DQE measures the fraction of the incident radiation captured in producing an image, along with how well the image chain keeps track of where each X-ray hit the detector, thereby capturing the spatial intensity variations in the object being imaged. In medical terms, this translates into measurement of the efficiency of X-ray dose utilization and the ability to represent the features and details in the X-ray scene. Improved DQE can be used for enhanced image quality or reduction in dose. Figure 1 illustrates the DQE improvement recently achieved with the introduction of a new cardiac flat-panel detector, and the relationship between DQE and the frequency “signature” of a coronary artery stent. $DQE(0)$ of the Innova 2100 detector is 79%, an 11% improvement over the previous detector. Note that the range of spatial frequencies over which the DQE is most improved matches the range of frequencies over which the stent provides most of its signal. Figure 2 illustrates how the DQE of this new detector holds up even better at lower fluoroscopic doses, a key characteristic of flat panel detector performance. Fluoroscopic $DQE(0)$ of the Innova 2100 detector is 73%, a 15% improvement over the previous generation detector. The benefits of these improvements in terms of improved image quality at reduced doses will be published shortly [3].

Dynamic range Dynamic range can be defined as the ratio of the highest X-ray intensity that can be usefully detected, processed and displayed to the noise in the image with no signal (totally dark area) in a given imaging mode. Clinically, it corresponds to the ability of an imaging system to show small contrast differences or details over a range of anatomical attenuation, such as when viewing the lung, spine and liver in the same image. The implications for image quality are fairly obvious: the need for repositioning, wedge filter adjustments, etc., is minimized because the system is more forgiving to errors in collimation and positioning in general. So there is an advantage for dose reduction, as well, in terms of being able to see what is needed without many adjustments or retakes. (Although there are no universal standards for defining and measuring dynamic range, some standard phantoms provide a range of attenuation over which a low contrast object is placed. The NEMA 21 phantom [4, 5] contains such a test pattern with an associated measurement called Working Thickness).

Temporal resolution X-ray imaging, particularly in pediatrics, frequently involves anatomical scenes that are changing with time, either because the anatomy is moving

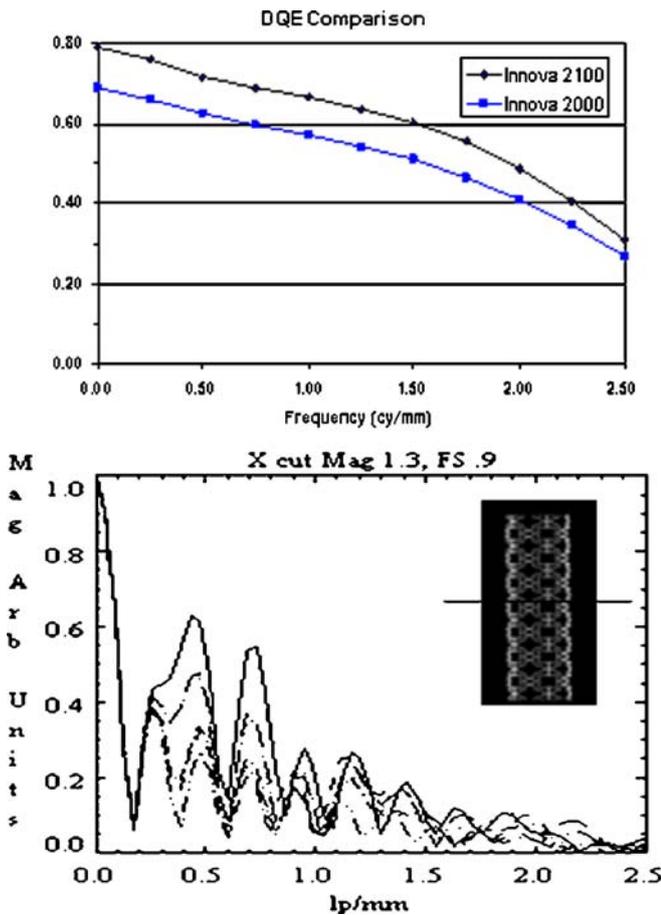


Fig. 1 Top DQE(f) of Innova 2100 vs. Innova 2000 flat-panel detector. Bottom Spatial frequency content of a stent. Note that there is progressively less stent signal at higher frequencies. So Innova 2100 DQE improvement is well-matched to stent signal. DQE(f) measured at record level radiation exposure (3650 nGy). Stent is Cordis Palmaz-Schatz

with respect to a more fixed background, or because the detector is moved relative to the patient, as in an upper GI study. Temporal resolution characterizes the ability of a detector and imaging system to accurately capture and display such changing scenes. It is composed of two parts: the ability to adequately visualize the *objects* in motion, such as the beating chambers of the heart or great vessels, and the ability to adequately visualize the *motions* of the objects of interest, such as the passage of barium in the esophagus because of peristaltic motion or the advancement of a guidewire or other interventional device for adequate hand-eye coordination. The performance specifications that typically arise from a consideration of temporal performance needs are frame rate, maximum exposure time, and lag. The desired specifications are highly dependent on the clinical applications. Optimizing the frame rate, exposure time and image processing parameters maximizes the imaging performance in dynamic imaging situations, thereby minimizing the dose required to achieve the desired clinical results.

Automatic exposure management systems

The Innova and Precision 500 D products are designed to automatically determine the optimal X-ray technique parameters (kVp, mAs, focal spot size, and spectral filtration) for a variety of operational modes, e.g., fluoroscopic, digital spot, DSA, and digital cardiac record. Such automation is referred to by the feature name AutoEx. Determination of the technique parameters is based on the cost-benefit relationship previously discussed. Basically, technique parameters are chosen that yield a targeted benefit (image quality) for the lowest cost (patient dose).

AutoEx is described in more detail with the aid of Fig. 3. AutoEx provides the link between patient information (deduced from the detector signal) and technique values to use (relayed to the generator and collimator). A two-step approach is employed. In step one, an equivalent patient thickness is determined based on the average dose to the detector and the technique values used for that exposure [6]. In step two, the technique parameters are determined for the next exposure using the patient thickness value and predetermined look-up tables. Design of the look-up tables (or “trajectories”) is based on the cost-benefit relationship of image quality and dose. Defining image quality as contrast-to-noise ratio (CNR), trajectory tables are designed to give a targeted CNR for the lowest possible patient entrance dose. An example table is shown in Fig. 4. This is an example of a fluoroscopic trajectory for adult angiography. The corresponding pediatric angiographic trajectory employs a shorter pulse width of 4 ms maximum for equivalent patient thicknesses less than 30 cm PMMA. Other constraints are also factored into trajectory design, such as maximum and minimum generator settings, X-ray tube capabilities, regulatory dose limits, etc. A trajectory table is developed for each set of available system parameters (e.g., image magnification, frame rate, dose

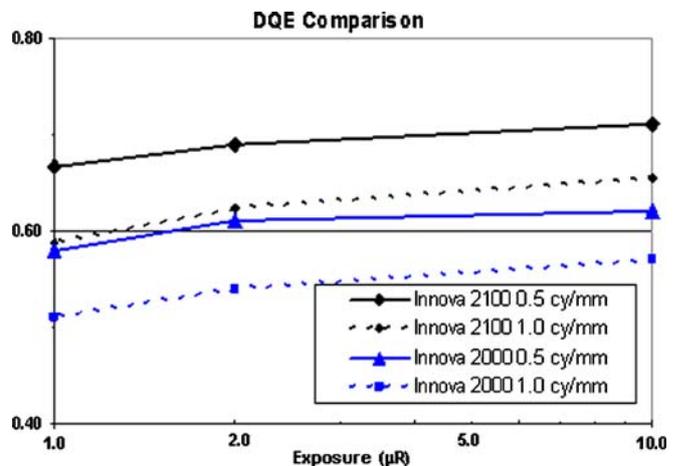


Fig. 2 DQE (0.5 and 1.0 lp/mm) of Innova 2100 and 2000 detectors as a function of exposure per image in the fluoroscopic range. Note significant improvement of Innova 2100 DQE at all dose levels. Realize that, even if average detector exposure is, say, 2 µR, dense parts of the image will deliver considerably lower exposure levels

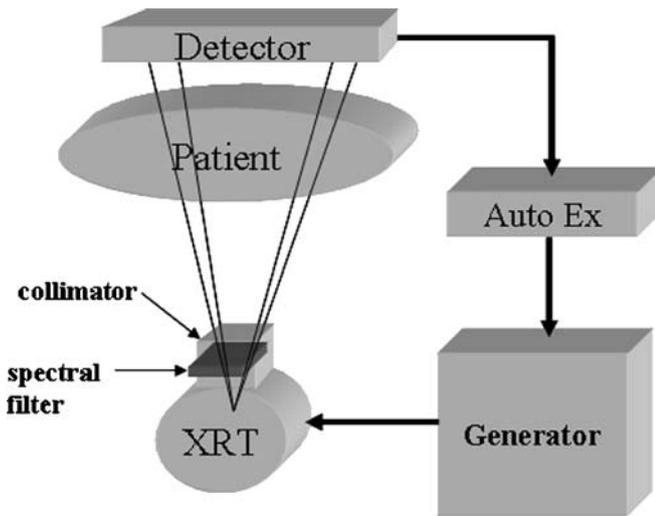


Fig. 3 Schematic illustration of the AutoEx controller within the X-ray imaging chain

level, etc.) for each operational mode (e.g., fluoroscopic, spot, DSA, etc.). This provides a great deal of flexibility in design and also enables enhancement of system performance via periodic software upgrades.

In order to fit the needs of different clinical applications, regional regulatory norms, and varying preferences of clinicians, several trajectory families are offered with the Innova and Precision 500 D products. Such families typically feature different dose levels and related optimization criteria. Figure 5 lists the offerings for the Innova 4100 and their typical dose levels. The first dose customization is performed at installation; one of five AutoExposure preferences is selected that best fits the needs of the customer. In addition, the user can select at installation between two distinct strategies for dose reduction in lower frame rate fluoroscopic modes. The first option, called “Maximum Dose Reduction”, uses the same X-ray techniques for 15 fps and 7.5 fps as it would in the case of 30 fps, thus reducing the dose by factors of 2 and 4, respectively. Because of the characteristics of human visual perception, the application of this strategy results in a reduction of the perceived image quality in the lower frame rate modes compared to the 30 fps mode. The second option, “Balanced IQ/Dose”, provides similar perceived image quality for all frame rates, which can be obtained by reducing the dose corresponding to 30 fps fluoro to approximately 75% for 15 fps and 50% for 7.5 fps [7]. For the families and frame rates offered, a 20:1 range of doses

Mode = fluoro, 30 pulses per second						
thickness	Technique				Pat Dose	Det Dose
cm	kVp	pulse width	peak mA	Cu filter	R/min	mR/min
15	73	8.0	8.3	0.2	0.41	3.6
20	73	8.0	27.4	0.2	1.29	3.6
25	77	11.8	36.6	0.1	4.16	3.6
30	95	12.4	34.3	0.1	10.00	3.6

Fig. 4 An excerpt from one trajectory table, in this case a 30 fps adult angiography fluoro mode in the 20-cm field-of-view of an Innova system. The corresponding pediatric table has a pulse width of 4 ms maximum for an equivalent patient thicknesses of less than 30 cm PMMA

can be achieved. Figure 6 lists the trajectory families offered with Precision 500 D and typical dose levels. Families are offered for adult and pediatric modes. The pediatric mode is further divided into “grid out” and “grid in” modes. The grid out mode is primarily for young children, where the grid is kept out because of the lower scatter-to-primary ratio for dose reduction. The grid in mode is provided for larger children and adolescents, where scatter can cause significant image quality degradation and necessitates use of the grid. The maximum dose rate for both pediatric trajectories is 5 R/min, while for the adult trajectory it is 10 R/min. In all trajectory families, the variation in dose rate with frame rate follows the recommendations of Aufrecht et al. [7]. Finally, trajectories are also developed to meet specific country regulations. The German trajectory is shown as an example. A dose range of about 6:1 is spanned proceeding from the adult trajectory family (30 fps) to the pediatric grid out family (3.75 fps). Including the German trajectory family would present an even larger range.

The control of dose with field-of-view has evolved as imaging chains have become more sophisticated. In early image intensifier-based systems, the average entrance dose to the intensifier varied inversely with the field-of-view as a result of the decrease in gain of the intensifier with smaller fields-of-view (and the fact that no further compensations were made in the automatic brightness control loops). As a result, patient skin dose would increase significantly when using smaller fields-of-view. Of course, image quality improved, as well, as a result of the higher signal-to-noise ratio associated with a higher X-ray photon flux. However, as image systems became more sophisticated, it became possible to separate any need for higher image quality with smaller fields-of-view from the behavior of an imaging component. On the subject of the need for higher image quality with smaller fields-of-view, there is a spectrum of opinion with two extremes. At one end is the belief that dose does not need to be changed with field-of-view, which is consistent with the way that traditional film/screen cassettes inherently behave. (But bear in mind that films are not magnified for display.) The only consideration in deciding on dose should be the signal-to-noise ratio required in the image. At the other end of the spectrum is the belief that the *perceived* signal-to-noise ratio in the *displayed* image should be kept constant. Simply magnifying the image, without increasing the dose, will tend to improve the visual performance of the clinician, which will also make the noise in the image more apparent and often objectionable. Perhaps implicit in this belief is that the selection of smaller fields-of-view implies a desire to see smaller detail and smaller contrast differences, which is improved by increasing the dose. GE has chosen to consider both of these opinion camps in the design of its current fluoroscopic systems, by adopting a general principle of varying the dose inversely with the *linear dimension* of the field-of-view, e.g., diameter or edge. The logic is that some increase of dose is warranted in selecting smaller fields-of-view, but not as much as $1/\text{area}$. Imagine, for example, threading a guidewire and catheter from the

Trajectory Family	Fluoro 30fps mGy/min	Cardiac uGy/fr	Dyn 5 fps uGy/fr	DSA mGy/fr
IQ Plus (IQP)	Normal : 21.8 Low : 9.4	Normal : 91.2 Low : 32.4	Normal : 293 Low : 146	Normal : 2.0 Low : 1.0
IQ Standard (IQS)	Normal : 25.2 Low : 10.4	Normal : 91.2 Low : 35.2	Normal : 293 Low : 146	Normal : 2.0 Low : 1.0
Smart IQ (SIQ)	Normal : 14.9 Low : 5.7	Normal : 91.2 Low : 32.4	Normal : 293 Low : 146	Normal : 2.0 Low : 1.0
Receptor Dose Limited Plus (RDLP)	Normal : 18.7 Low : 7.7	Normal : 32.4 Low : 14.3	Normal : 293 Low : 146	Normal : 1.0 Low : 0.5
Receptor Dose Limited Standard (RDLS)	Normal : 9.7 Low : 4.0	Normal : 32.4 Low : 14.3	Normal : 293 Low : 146	Normal : 1.0 Low : 0.5

Fig. 5 Typical patient entrance skin exposure levels for fluoro and three record modes for the five different AutoEx trajectory families offered on the Innova 4100. Conditions are 20-cm field-of-view, 20-cm PMMA phantom

groin to the aortic arch using the largest field-of-view afforded by the system for speed, followed by use of a smaller field-of-view to perform the maneuver of entering the vertebral artery from the arch. One could argue that a significantly higher level of image quality is warranted in the latter case compared to the former. And, in any case the clinician is afforded several dose selections in every field-of-view, making it possible to follow the ALARA principle in any imaging situation.

Image processing techniques: impact on image quality/dose

Image processing techniques can have profound effects on the qualities of a displayed image produced from a given X-ray dose. In this section we discuss two important types of image processing, dynamic range management (DRM) and fluoroscopic noise reduction (FNR), through temporal filtering.

Dynamic range management The importance of the dynamic range of the image system for imaging and dose performance is explained in Section 1. Figure 7

illustrates the improvement in dynamic range that has come with the introduction of flat-panel detector technology. The range of X-ray signal intensity that can be encoded significantly exceeds that of a high-performance digital video camera. However, in order to take advantage of the improvement it is necessary to find a way to display the full range of data without losing details of subtle contrast. This is the classic conundrum of the “wide latitude” versus “high contrast, short gray scale” film/screen choice. A patented GE proprietary image-processing algorithm called dynamic range management (DRM) overcomes this conflict by reducing the impact of large anatomical structures on displayed image intensity variations without reducing the contrast of small details in the image. This is illustrated in Figs. 8 and 9. Note that anatomical details are visible from the densest portion of the anatomy to the skin line, without blackout or white saturation. DRM processing operates in real time in all fluoroscopic and non-DSA record sequences. It adapts to each image in real time based on the brightness levels in the scene. By providing enhanced visualization of the wide range of data acquired by the flat-panel detector, it avoids the need to readjust imaging conditions, thereby allowing savings in procedure time and radiation exposure.

Trajectory	Typical Fluoro Dose (mR/min)		
	Continuous	7.5 fps	3.75 fps
Adult (grid in)	12	5.8	3.3
Pediatric - Grid 'in'	8.4	3.8	2.2
Pediatric - Grid 'out'	6.4	3.2	1.9
Germany-Specific (grid in)	3.7	1.9	1.1

Fig. 6 Typical patient entrance skin exposure rates for various trajectory families. Values are taken from the trajectory tables for a 20-cm field-of-view and a 20-cm thick patient. The dose values for the Germany-Specific trajectory are lower with the grid removed

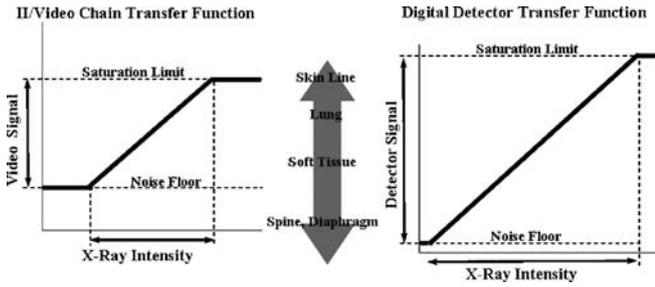


Fig. 7 An illustration of the increase in image intensity dynamic range provided by digital flat-panel detector technology over image intensifier/video technology. Note that the range of X-ray signal intensity that the digital detector can encode without saturation is significantly higher, as is the range of intensity encoded in the output signal

Fluoroscopic noise reduction with motion compensation

At fluoroscopic dose levels, both the Innova and Precision 500 D products use a noise-reduction processing algorithm to mitigate the amount of quantum noise perceived in the fluoroscopic sequence. Such processing, referred to by the acronym FNR (fluoroscopic noise reduction), functions in the following manner: Prior to display of the most current (or live) image frame of a fluoroscopic sequence, the FNR algorithm averages a number of previous image frames for each pixel. Averaging is performed in a recursive manner, i.e., a percentage of the live frame, X_{live} , is added to a percentage of the previously displayed frame, X_{prev} . (Note the sum $X_{live} + X_{prev}$ must equal 100.) In this implementation, the effective number of averaged frames, N_{eff} , is given by the relation:

$$N_{eff} = \frac{200}{X_{live}} - 1 \tag{1}$$

For a quantum-limited system, the noise reduction achieved (relative to no averaging) is to a good approximation equal to $1/\sqrt{N_{eff}}$. Using these relations, it is apparent that significant noise reduction occurs for small values of X_{live} . For example, for $X_{live} = 20\%$, $N_{eff} = 9$

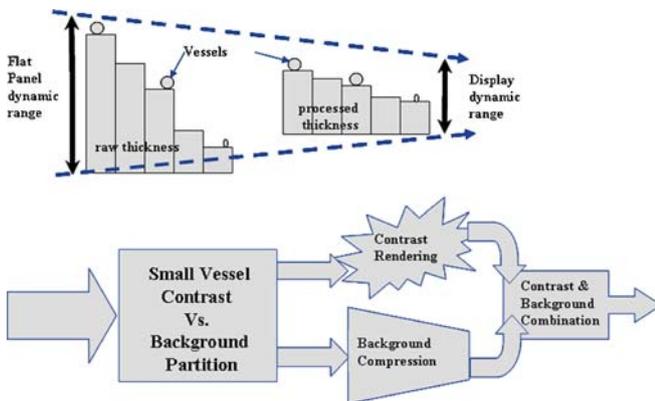


Fig. 8 An illustration of how the DRM algorithm compresses the large dynamic range of the original image while preserving the contrast consistency/visibility of structures of interest

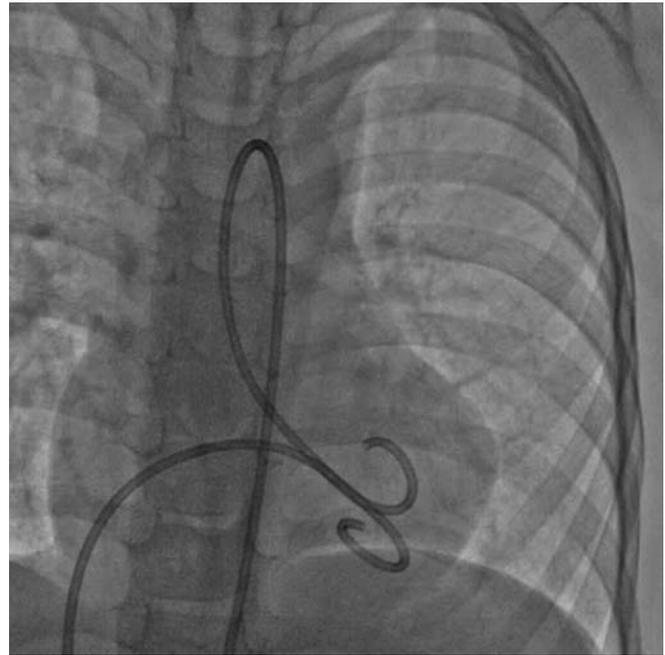


Fig. 9 Pediatric thoracic image demonstrates combined effect of wide dynamic range of digital flat-panel detector plus DRM processing. Note that details are visible from spine out to skin line, at good contrast levels

(using Eq. 1), and the noise reduction is $1/\sqrt{9}$, or 0.33. This means that the apparent noise in the FNR-filtered image sequence would be the same as an unfiltered sequence at a nine-times higher dose.

The noise reduction achieved by FNR comes at the expense of increased motion blurring artifacts in the image. If anatomy is moving on a frame-to-frame basis, averaging a number of those frames will cause undesirable blurring and/or multiple images of moving features. The advanced FNR algorithm employed by GE mitigates these undesirable effects by employing motion compensation. Motion compensation varies N_{eff} , depending on the degree of motion deduced for a given pixel. Motion is deduced by comparing the pixel value for the live frame with the previously displayed frame, and the value used for X_{live} is dependent upon the difference, denoted as Δ . Typically for large Δ , X_{live} is set to a larger value, thus decreasing N_{eff} and the amount of temporal filtration applied. For small Δ , X_{live} is set to a smaller value, increasing N_{eff} . In such a manner, noise reduction is achieved across the entire image but in a manner that does not present the distracting effects of blur and multiple images. By reducing quantum noise in this way, FNR is consistent with the ALARA principle in that it enables lower dose operation.

In order to satisfy different clinician preferences and to be effective for the various clinical modes of operation, a variety of FNR settings are available for the Innova and Precision 500 D products. Each setting can be thought of as corresponding to a different mapping of N_{eff} versus Δ . In the Innova products, a unique setting can be made in each user-defined procedure protocol. FNR settings are also

automatically linked to clinical operation. For example, with lower frame rate, the likelihood of significant anatomical motion between consecutive frames increases. Therefore, the preferred mapping of N_{eff} versus Δ can be set differently as a function of frame rate.

System features: impact on dose

In this section we attempt to provide a comprehensive list of all the features that exist for dose management and minimization. We provide more complete explanations of those features that have not been discussed in previous sections.

Predefined procedure protocols These contain the default X-ray technique and other parameter selections for each clinical procedure defined by the user. For instance, the user can define the default field-of-view, fluoroscopic and record dose levels, frame rates, DSA run times, and associated fluoroscopic and record image processing parameters for each procedure. They can be customized so that each physician can have his/her own special procedure protocols.

Automatic spectral filters Various thicknesses of copper located within the collimator can be inserted in the X-ray beam under AutoEx control. Such filtration removes the lower energy photons, which typically do not contribute to the image (as they do not penetrate through the patient) but do contribute to the patient skin dose. Copper filters of thickness 0 mm, 0.1 mm, 0.2 mm, and 0.3 mm are available on the Precision 500 D product. The same is true for the Innova products, but with additional selections of 0.6 mm and 0.9 mm on the Innova 2100. Insertion of filters is automatic and integrated with the AutoEx trajectory design, following the principle of achieving a targeted image quality for the lowest possible patient dose.

Pulsed, variable frame rate fluoroscopic (linked to Procedure Protocols) This feature allows the frame rate to be programmed into a predefined protocol. Therefore, a frame rate consistent with the lowest dose and sufficient for the clinical task is automatically selected for the various studies. This feature is available for both the Precision 500 D and Innova products. Pulse rates available on the Precision 500 D are 15 fps, 7.5 fps and 3.75 fps. The Innova 2100 offers 30 fps, 15 fps and 7.5 fps.

Dose display to operator The AutoEx function calculates the skin dose and DAP based on technique, spectral filtration, and collimated radiation field size. These values are displayed on the in-room monitor and stored with each patient's examination data. For the Precision 500 D, skin dose is calculated at tabletop. For the Innova products, skin dose is calculated at the IEC interventional reference point for C-arms with variable SID, which is 15 cm back toward the X-ray tube from the mechanical isocenter. When exposing, dose rate is displayed; otherwise, cumulative dose is displayed.

Virtual collimation This feature allows the operator to preview collimation changes on the last displayed fluoroscopic image rather than using live fluoroscopic, thereby conserving dose.

Adjustable contour (wedge) filters in collimator These partially transparent, tapered radiation filters, positioned by the operator, allow for reduction of exposure to thin sections of the anatomy, thereby reducing dose and producing a more uniform intensity image.

Last-image-hold After a fluoroscopic sequence, the last fluoroscopic image is displayed or held on the monitor and can be stored, thus enabling the possibility of avoiding a higher-dose digital spot exposure.

Fluoroscopic loop replay and store (DICOM & DVD Record) Both Precision 500 D and Innova provide fluoroscopic loop storage and replay. DVD recorders are also compatible. These generally provide better image quality than VHS tape. Recorded fluoroscopic loops can often be used in place of higher-dose record or digital cine sequences, thereby reducing procedure dose.

Auto (Precision 500 D) and manual (Innova) grid removal Grid removal can be an effective dose reduction technique in low-scatter imaging situations, as when imaging thin anatomy in smaller fields-of-view. The Precision 500 D provides a feature whereby the default grid position is controlled (either in or removed from the X-ray field), for all examinations. Pediatric sites generally opt for the grid to be removed by default to reduce dose. In addition, both the Precision 500 D and Innova products allow the clinician to insert or remove the grid during an examination, allowing the clinician to control dose and image quality as necessary.

Patient contouring (automatically minimizes SID) This feature, available on the Innova 2100 and 3100 products, provides automatic minimization of the distance between the detector and patient after every gantry movement, using the integrated, advanced capacitive anticollision system to target a 2.5-cm gap between detector and patient exit skin surface. Reduction in patient entrance dose has been estimated to be 3–14% [8].

Advanced applications: impact on dose

New imaging techniques can also have significant impact on patient dose. Two are discussed here: Innova Spin and Innova Chase. Innova Spin is a rotational acquisition technique utilizing DRM image processing discussed above to prevent image burnout in the lung and at skin boundaries during the rotation. It has been found that rotational acquisition sequences can replace several fixed-angle acquisition sequences, thereby saving radiation dose and contrast medium. This has been demonstrated both in adult coronary angiography and pediatric patients [9, 10].

Innova Chase, originally designed as an unsubtracted bolus chase technique, also utilizes DRM processing to prevent image burnout and blackout while panning over the abdomen and extremities. The Innova Chase technique has been found to be useful in reducing adult dose in uterine fibroid embolization (UFE) procedures compared to DSA [11, 12], without compromising clinical image quality. The latter result occurs because the DRM processing reduces the black to white variation in the image without reducing vessel contrast, something that DSA does extremely well, but without the possibility of misregistration artifacts. It is, therefore, reasonable to propose that this technique could also be useful in pediatric procedures where patient motion often limits the performance of DSA.

Conclusion

We have described the dose management characteristics and features of several GE Healthcare fluoroscopic products used in pediatric imaging, along with the underlying design philosophy of imaging dose efficiency, optimization, and choices provided to the operator. It should be clear that many aspects of the system can contribute to dose minimization, from component characteristics such as detector DQE and X-ray source efficiency to system design elements such as procedure protocol-driven Automatic Exposure Control and advanced image processing, to advanced applications such as Innova Spin and Innova Chase. Today's state-of-the-art systems have reached a high level of sophistication, but there remains room for improvement, particularly as system applications are adapted to new interventional procedures and information from other imaging modalities becomes integrated into the X-ray laboratory.

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