WHITE PAPER

Technical Brief Series

Maximizing Dose Efficiency for Pediatric Patient Imaging

Addressing Pediatric Imaging Challenges with Carestream Solutions

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Addressing Pediatric Imaging Challenges with Carestream Solutions: Maximizing Dose Efficiency for Pediatric Imaging

Introduction

Best practices of radiographic imaging follow the principle of using a dose "as low as reasonably achievable" or ALARA,[1] which balances the needs of the patient (lower dose) with the necessity of producing an image with quality suitable for confident exam interpretation. While dose level is a major aspect of managing dose efficiency for the pediatric population, there are other important considerations that also require awareness. Radiographic imaging of pediatric patients presents several unique challenges compared to the imaging of adults. Increased radiation sensitivity of growing organs and bones, children's longer expected lifespans and the large range of body habitus encompassed by this patient demographic all mean that it's not appropriate to use the same acquisition techniques and image-processing parameters used for adult imaging. The Image Gently campaign's "Back to Basics" initiative encourages the use of pediatric-specific imaging practices and is completely consistent with the guiding principles in Carestream's approach to these important issues.[2, 3, 4]

To provide the highest quality image with the most efficient use of the radiation exposure, it's important to address each step in the image-formation chain as part of a complete system. The image-formation process can be naturally divided into three distinct stages: image acquisition, image processing for display, and image review and assessment. These steps are represented in Figure 1. The process of image-quality assessment and its essential role in driving positive feedback into the acquisition and image-processing steps are also indicated in this figure.

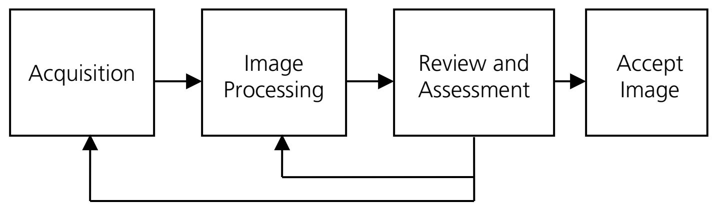

Figure 1. Flow diagram for the image-formation process. Image review and assessment allow for feedback into the acquisition and image-processing steps, which can drive continued improvement.

Image Acquisition

Capturing the X-ray image with the image receptor is the first stage of image formation. The introduction of Carestream's wireless DRX detector products has been a major step forward in the provision of a high-quality X-ray detector that fits seamlessly into the workflow of the NICU and pediatric ICU. In addition, the use of a cesium scintillator layer helps to ensure the best possible image quality. The design virtually eliminates the problems that can be encountered with patient positioning in a busy clinical environment when a tethered system is used. The replaceable battery also guarantees that the detector is ready for use at a moment's notice. The CARESTREAM DRX Plus 2530C panel is a small-format, high-resolution (0.100 um pixels spacing), high-detective quantum-efficiency (DQE) panel that fits easily into a neonatal incubator X-ray tray and is ideal for tabletop extremity exams.

In addition to using a highly efficient detector, it's also essential to use the appropriate acquisition techniques (e.g. kVp, mAs and filtration) across the wide range of pediatric body habitus. This range of body sizes – from the smallest neonatal patient to the largest adolescent – requires acquisition techniques to be tailored to each patient's size and age. To help with this challenge, Carestream offers the ability to select the pediatric patient body size (optionally based on weight or age) from a range of seven categories, which is an expansion of size categories recommended by the FDA.[5, 6] The *Pediatric Capture Optimization and Enhancement option* allows the system to choose default acquisition parameters and image-processing configurations appropriate for different sizes of patients and different detector types. This capability provides a more consistent acquisition and display of images for patients within a given body size and age range.

One of the most significant recent Carestream advancements is *Smart Noise Cancellation (SNC),* which has a direct bearing on the selection of acquisition techniques. This new AI-based de-noising technique facilitates dose reduction across the board for all patient sizes and general radiography exams while preserving fine spatial detail.[7] Carefully designed reader studies have demonstrated that with a cesium iodide panel, acquisitions at 800 ISO speed with *SNC* applied were rated superior in image quality when compared to 400 ISO speed acquisitions without the use of *SNC*.[7] Likewise, for gadolinium oxysulphide (GOS) panels, acquisitions at 500 ISO speed were deemed superior when compared to corresponding 320 ISO speed exams without *SNC*. Overall, 99% of the low-dose image pairs with *SNC* were rated as good or better than the nominal dose images without *SNC*.[7] (Note: ISO speed has an inverse relationship to IEC exposure index. As exposure is halved, IEC EI is halved, whereas ISO speed is doubled.) And when *SNC* is coupled with other dose-management methods such as filtration,[8] even greater dose reduction can be achieved. Figure 2 demonstrates the benefit of *SNC* on a donated neonatal cadaver (IRB exemption granted), which was manually insufflated prior to each acquisition. Images were acquired on a DRX-1C panel (CsI scintillator) with 0.1 mm Cu filtration at 50 kVp. Effective dose was estimated by Monte Carlo-based dose-estimation software PCXMC v2.0.[9] The effective dose for the top left and bottom left images was 4 uSv and 8 uSv, respectively. Comparison of the 4 uSv effective dose with *SNC* (top right) versus the 8 uSv image demonstrates how *SNC* cleans up the noise and preserves the fine detail (suggest viewing at 300% for softcopy).

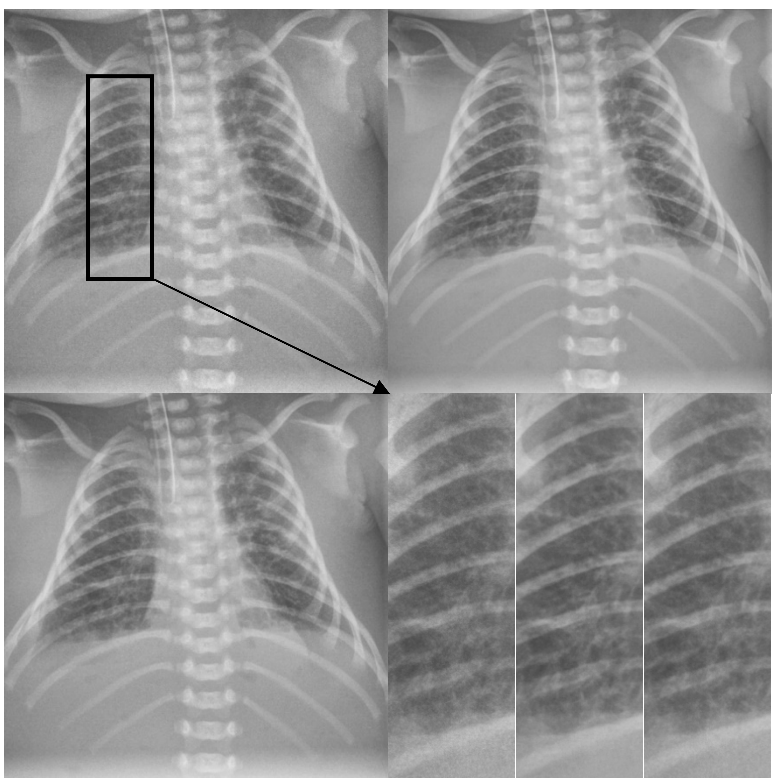

Figure 2. A neonatal cadaver (2313 g) chest image acquired on the DRX1-C panel, manually insufflated during each acquisition. Acquired at 50 kVp, 64" SID, 0.1 mm Cu filtration. Effective dose estimated by Monte Carlo-based dose-estimation software PCXMC v.2.0. Top left: 4 uSv effective dose, 4 mAs, default processing. Top right: 4 uSv effective dose image with *SNC* applied. Bottom left: 8 uSv effective dose, 8 mAs, default processing. Bottom right: enlargement of the three treatments (4 uSv default, 4 uSv with *SNC* and 8 uSv default).

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Figure 3 below compares the same pediatric hip image (acquired at 65 kVp, 1.3 mAs, 99.2 cm SID, grid, dose area product of 0.28, no filtration, IEC exposure index 83, ISO speed 800) both without (left) and with (right) *SNC*. Observe the preservation of fine detail with the removal of quantum noise. *SNC* significantly benefits image quality across all exams for both the DRX1 and DRX Plus family of detectors.

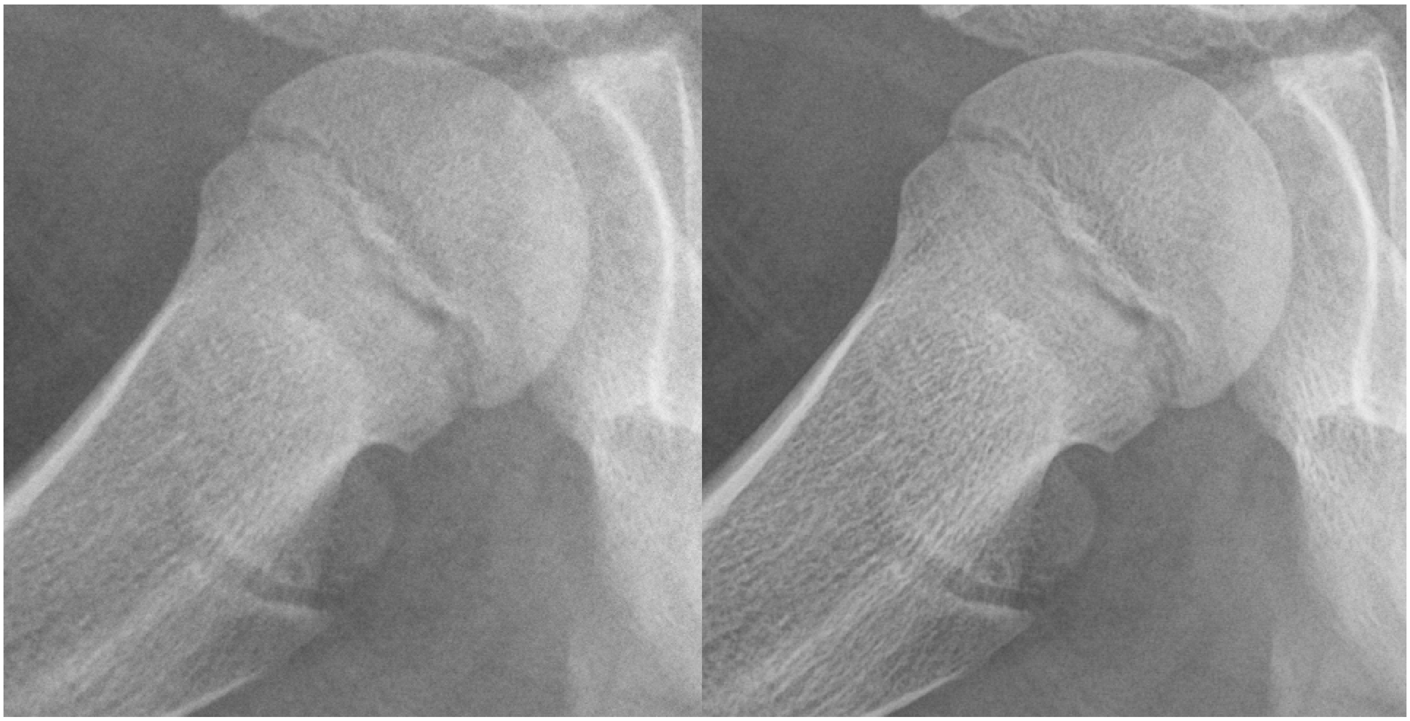

Figure 3. A pediatric hip frog view on the DRX Plus C (CsI) panel, 65 kVp, 1.3 mAs, 99.2 cm SID, grid, DAP 0.28, no filtration, IEC EI 83, 800 ISO speed. Left: without *SNC*. Right: with *SNC*.

When *SNC* is enabled, signficant dose reduction is possible and this impact should be considered when selecting technique factors. *SNC* coupled with the best practices promoted in the Image Gently campaign can provide maximum image quality at significantly reduced dose.

Carestream is also engaged in research to develop improved acquisition techniques for pediatric patients. This work is based on the realization that the use of a digital receptor opens the possibility for targeting a specific signal-to-noise ratio in the image, versus maintaining a specific optical density within the final image. The inherent separation of the acquisition and display of an image in the digital environment provides new opportunities to develop task-specific tailoring for the amount and type of radiation used to create digital images.

To illustrate the opportunity for technique optimization, Figure 4 shows a normalized image-quality metric (detectability index per unit of effective absorbed dose) for a 5-10 mm-sized lung nodule, as a function of patient weight. The results indicate that for smaller patients, a lower kVp can provide improved image quality for a given patient dose, while higher kVps are more beneficial for larger patients. The benefit of lowering the kVp to reduce the dose for neonatal exams has been clinically demonstrated by Schäfer.[10]

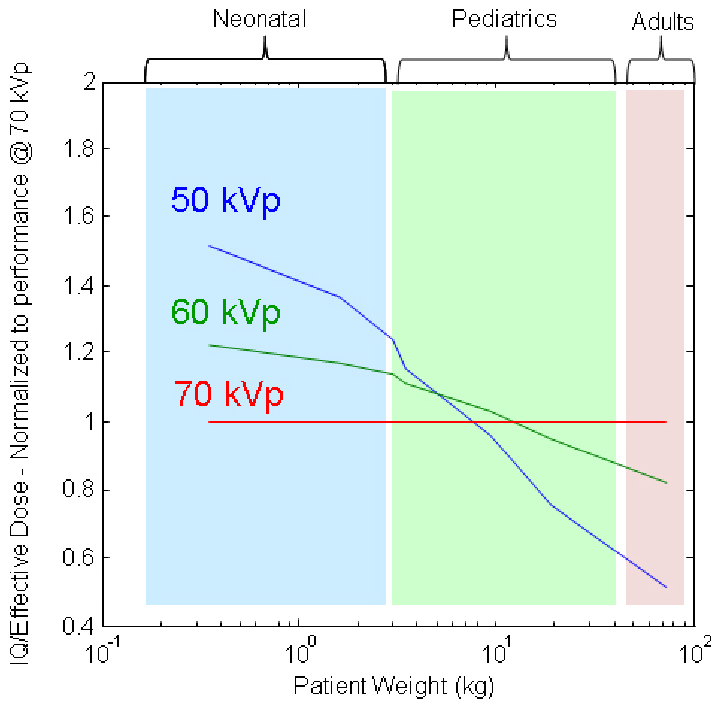

Figure 4. This graph shows the normalized image quality (nodule detectability index) per unit absorbed effective dose for different kVps as a function of patient weight for a 5-10 mm lung nodule. The data is normalized to the image quality result for the 70kVp case.

In certain procedures, such as scoliosis exams, it may be possible to reduce the exposure levels used for the follow-up images. Exposure reduction works if the imaging task can be satisfactorily achieved with an image that is noisier than the high-quality primary exam but still provides sufficient delineation of the spinal processes to allow accurate clinical evaluation.

Carestream now offers the *DRX-L* detector, 17″ x 51″, which is specifically designed for long-bone and spine imaging using single-shot exposures that enable fast image acquisition and preview, simplified workflow and reduced dose compared to multi-shot long-length imaging. While it's difficult to directly compare the multi-shot to single-shot LLI relative to radiation exposure, all things being equal (grid, SID, kVp and detector imaging performance), the multi-shot LLI method results in approximately 10% more dose overall and 100% more dose in the overlap anatomical regions. Considering the long hold time associated with multi-shot LLI, where patient motion frequently results in a repeat of the exam, the dose reduction from reduced repeats is also an important consideration.

X-ray scatter can significantly degrade image quality if it's not managed as part of the acquisition process. The use of an anti-scatter grid decreases the amount of scatter that reaches the imaging plate and improves image quality. But a major drawback of using a grid is the required increase in dose to the patient. Measuring patient thickness is highly recommended as part of selecting the optimal technique. Grids are appropriate for body part thicknesses greater than 12 cm, but in pediatrics, exceptions may be made for exams that contain a substantial amount of air, such as chest exams.[11] However, recent advances in image processing have replaced the need for using a physical grid with software-based scatter suppression. Carestream's *SmartGrid* processing now makes it possible to image pediatric patients without a grid, thereby lowering the radiation exposure to these patients. Figure 5 demonstrates *SmartGrid* and *SNC* processing on a child's abdomen (DRX Plus 3543 C, 65 kVp, 1.2 mAs, no grid, IEC EI 187, 400 ISO speed, dose area product 0.47).

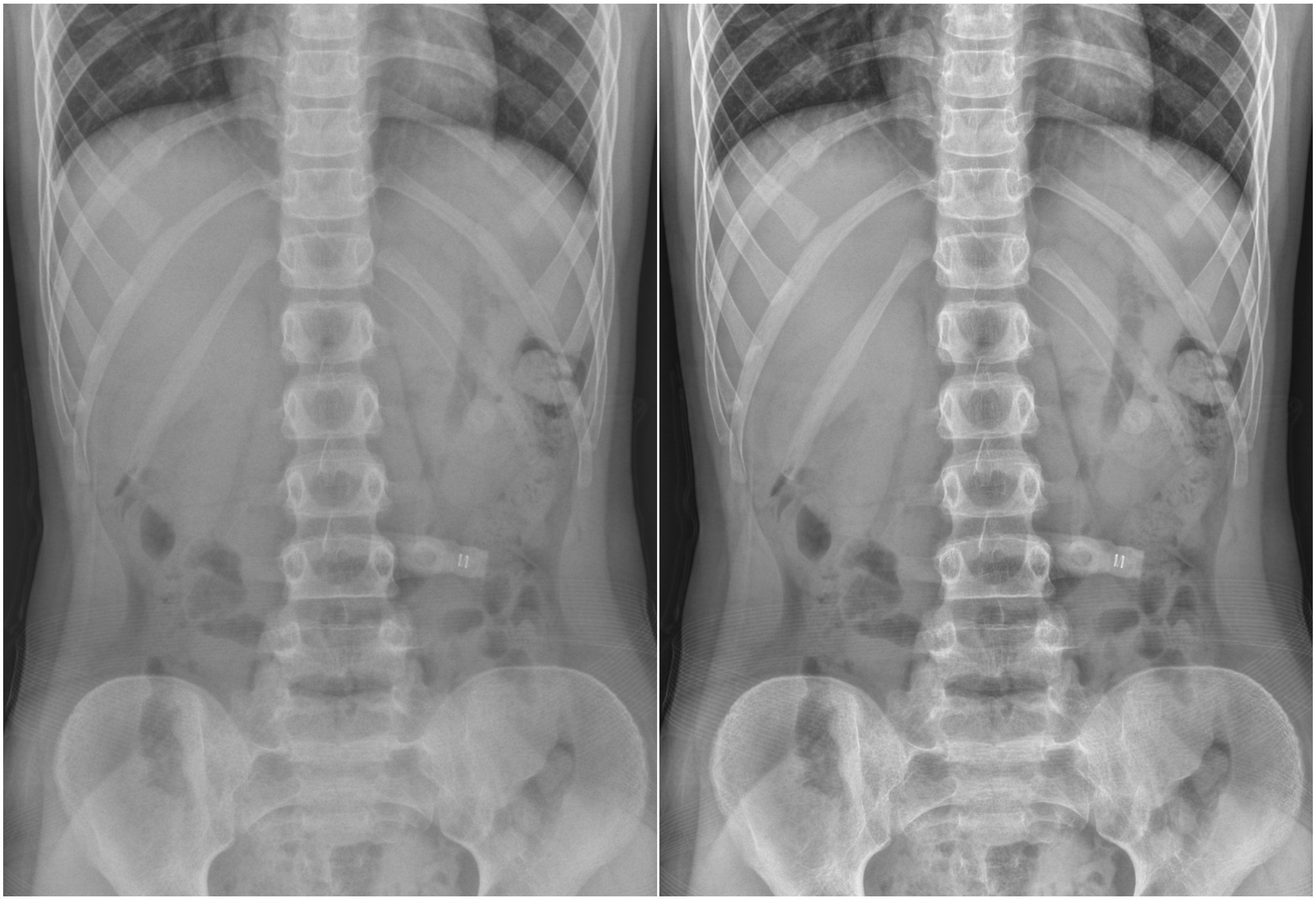

Figure 5. A child's abdominal image acquired on the DRX Plus 3543C at 65 kVp, 1.2 mAs, no grid, IEC EI 187, 400 ISO speed, DAP 0.47. Left: default processing; right: *SmartGrid* and *SNC* processing.

In the spirit of driving continuous improvement and consistency, Carestream's *Prior Image Review* feature enables technologists to review prior acquisitions of the patient on the console screen. Priors are pulled back from PACS (even from other vendors' equipment) as the radiographer is setting up the current exam. Previous positioning and technique factors can also be reviewed, enabling the technologist to learn and replicate the finer points of good previous studies. With the press of a button, the same techniques can be copied from a prior exam to the current exam, thus driving consistency between technologists.

Once an image has been acquired, rapid display of the preview image allows the radiographer to quickly decide whether the patient's anatomy was correctly captured or if the image needs to be retaken. This improves the speed and efficiency involved in completing exams, which is particularly important for young patients. To help, Carestream provides the *IEC Exposure Index* (EI) for quick assessment of the amount of radiation used to create the image.[12, 13] The associated *Deviation Index* (DI) allows an immediate evaluation of the acquisition technique compared to the institutional exposure target for the specific exam. This instant feedback, coupled with the other developments in technique selection described above, helps the radiographer provide more consistent image quality from the detector to the next step in the imaging chain – image processing.

EVP Plus Image Processing and Display

Once a high-quality image has been acquired at the lowest possible patient exposure, it's essential to perform appropriate image processing that presents the diagnostic information clearly and most efficiently to the radiologist. *Carestream's EVP Plus Software,* powered by our *Eclipse* image-processing engine,[14] can be tailored to adjust the image-processing parameters to an individual site's preference. When coupled with the *Pediatric Capture Optimization and Enhancement option*, the image-processing parameters can also be adapted to display the clinical information features in a more informative way compared to using adult image-processing configurations.

The multi-band frequency decomposition, with either traditional noise reduction or *SNC*, if enabled, and controlled edge-restoration capabilities mean that the available clinical content of the bony structures in the smallest NICU patients can be appreciated as well as the trabecular detail of older, more developed patients, as one example. The fine detail and lower contrast of the smallest NICU patient's anatomy require accentuation of different frequency components than those of larger adolescents. Figures 6 and 7 illustrate these differences and show the improved visualization provided by careful selection of the appropriate image-processing parameters.

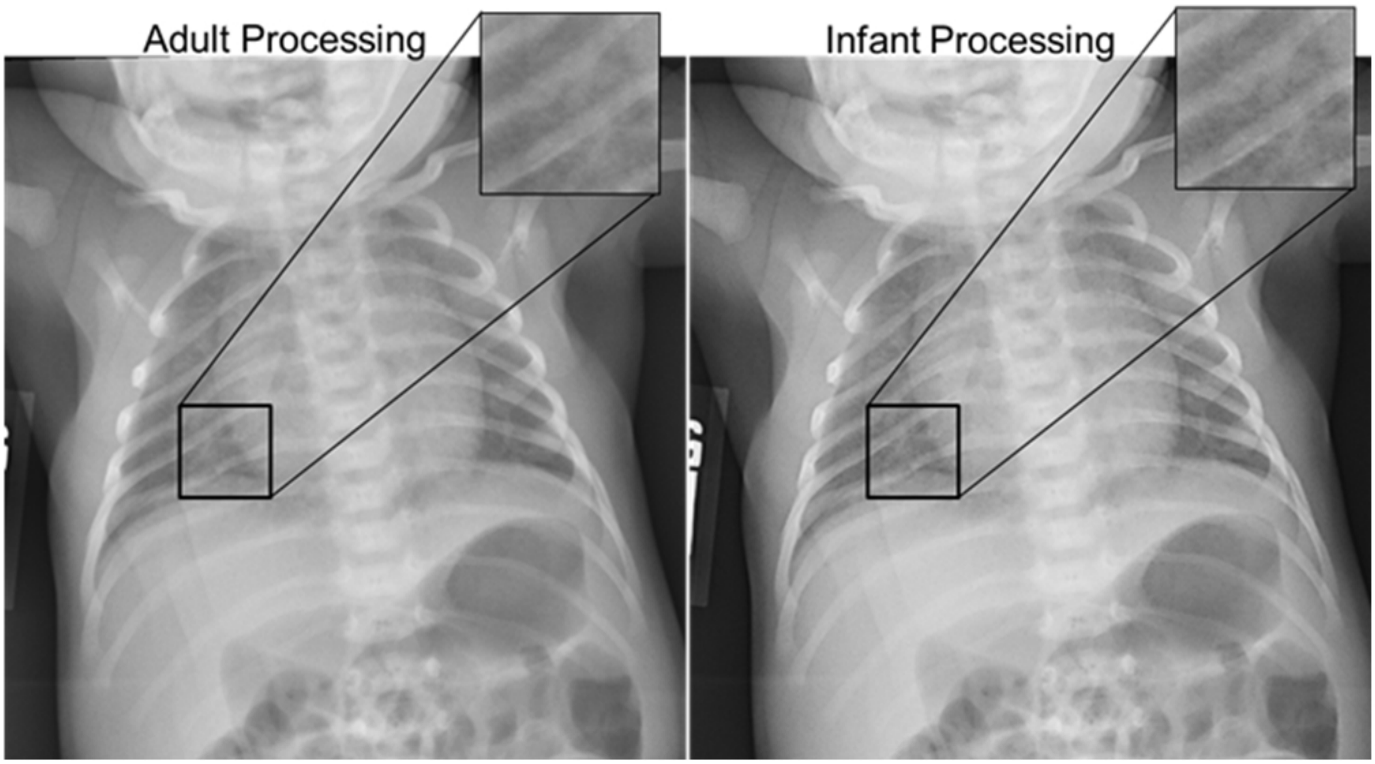

Figure 6. An infant chest image processed with both adult (left) and infant (right) image processing. Note that many infant chest details are not apparent when using adult processing.

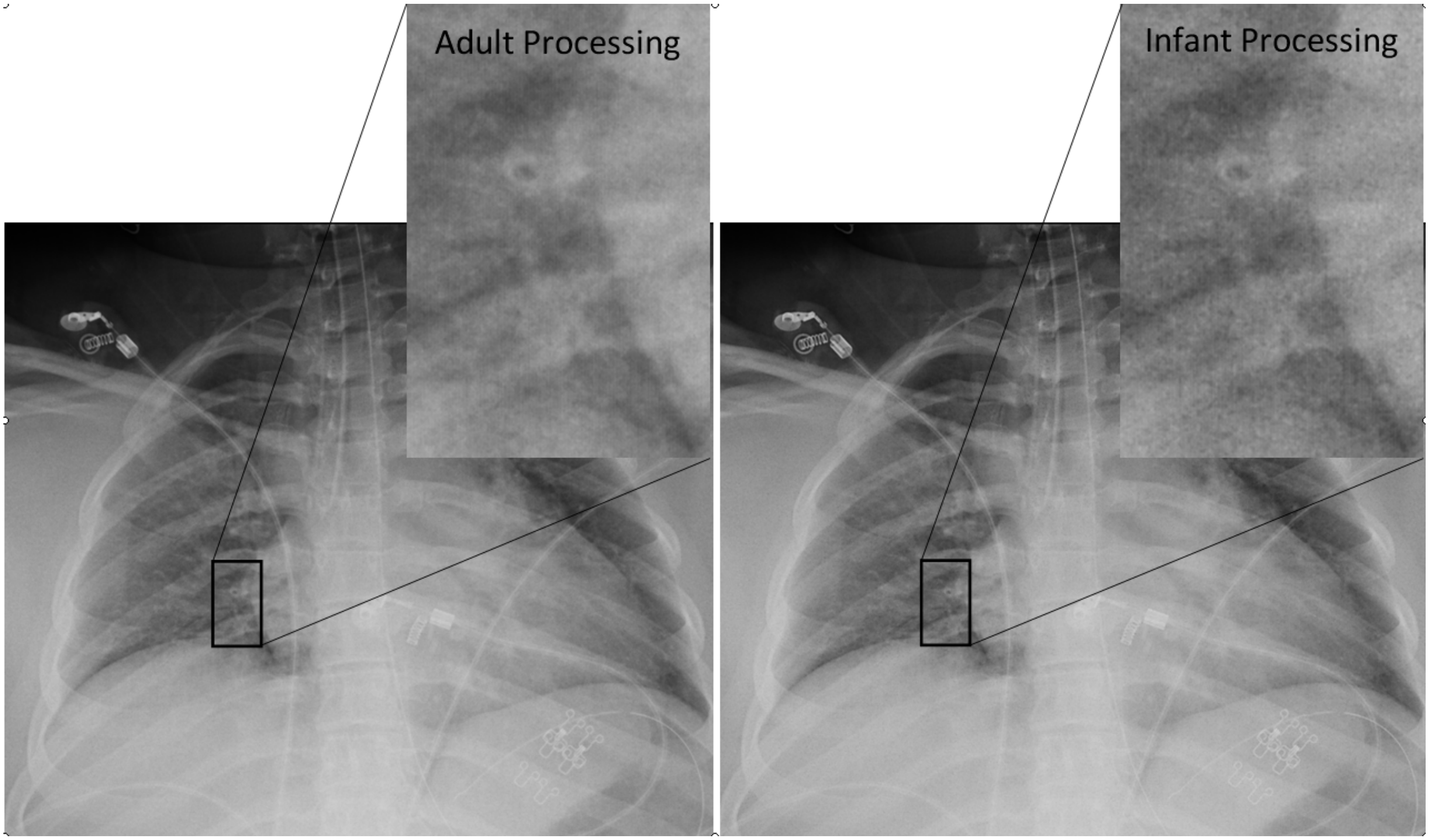

Figure 7. A teenage chest image processed with both adult (left) and infant (right) image processing. Note that fine details of the teen chest are overemphasized when using infant processing.

Tube and Line Visualization, available for all patient sizes, uses a companion image automatically created from the original acquisition with optimized processing for clearer, easier visualization of lines. Examples include a peripherally inserted central catheter (PICC), central venous catheter, and tubes, such as nasal gastric (NG) and endotracheal (ET), which help to avoid repeat imaging. Figure 8 (next page) demonstrates the *Tube and Line Visualization* (DRX 2530C detector, 58 kVp, 1 mAs, 152 IEC exposure index, dose area product 0.038). Observe how the PICC line in the upper right lung stands out, along with the ET and NG tubes.

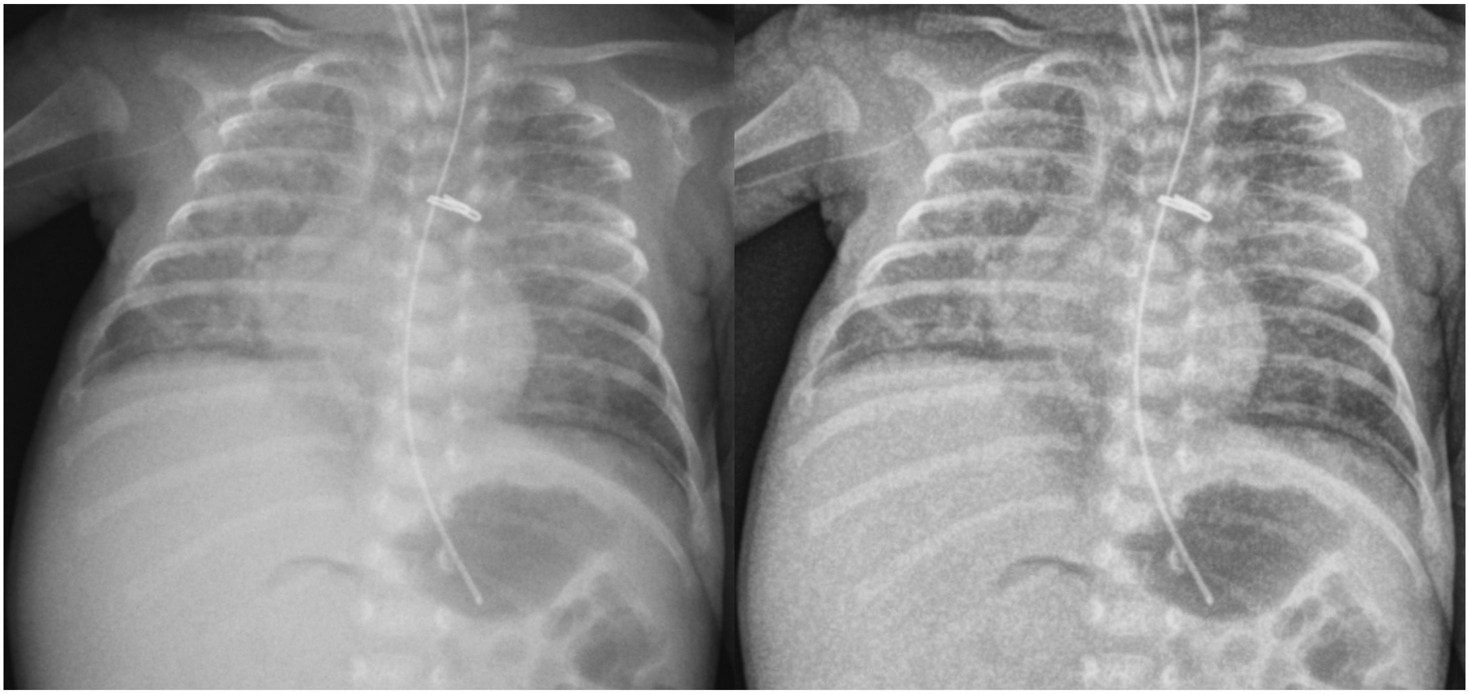

Figure 8. ***Tube and Line Visualization*** **(DRX 2530C, 58 kVp, 1 mAs, 152 IEC EI, DAP 0.038). Note the improved visualization of the PICC line (upper right lung), and ET and NG tubes.**

Quality Acceptance and Control

Once an imaging system has been installed and tailored to a site's preferences for patient exposure and image "look," it's important to have an ongoing quality control (QC) program in place that ensures the continued high quality of the images delivered to the reading radiologist. There are multiple aspects to this type of QC program and Carestream Health has implemented several system capabilities that enable a site to easily track many of the important parameters.

At the front end, the *DR Total Quality Tool (DR TQT)* package allows for efficient evaluation of the digital X-ray detector's current performance level. In addition, the IEC EI allows quick evaluation of the exposure levels used to acquire the images. On a departmental level, the *Administrative Reporting and Analysis Software* allows the QC technician or physicist to query all the Carestream systems across the institutional network from a single, central location. This can quickly highlight anomalous exposure levels, high repeat rates or other image-quality issues that may develop and provides opportunities to identify and resolve problems at an early stage. Together, these system capabilities can help technologists maintain their high level of image quality and consistency to facilitate reliable diagnoses.

Carestream supports DICOM Radiation Dose Structured Reports, enabling institutions to track and monitor all irradiation events.

Conclusion

The unique demands of pediatric imaging require a system-wide approach to guarantee high-quality imaging at the lowest possible exposure for young patients. Carestream Health offers a range of features and functionality that ensure our systems can provide the best and safest possible X-ray imaging across the full range of clinical exams for all pediatric patients.

[1] Miller, Donald & Schauer, David. (2015). The ALARA principle in medical imaging. AAPM Newsletter. 40. 38-40.

[2] Bulas DI, et al. AJR Am J Roentgenol. May 2009; 192(5):1176-8. Image Gently: Why We Should Talk to Parents about CT in Children.

[3] AJR Am J Roentgenol. May 2009; 192(5):1169-75. Image Gently Vendor Summit: Working Together for Better Estimates of Pediatric Radiation Dose from CT. Strauss KJ, et al.

[4] Image Gently®: The Alliance for Radiation Safety in Pediatric Imaging. http://www.pedrad.org/associations/5364/ig/ (Accessed September 27, 2012).

[5] FDA guidance entitled "Premarket Assessment of Pediatric Medical Devices," May 14, 2004. http://www.fda.gov/downloads/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/UCM089742.pdf.

[6] FDA guidance entitled "Guidance for Industry and Food and Drug Administration Staff: Pediatric Information for X-ray Imaging Device Premarket Notifications," November 28, 2017. https://www.fda.gov/regulatory-information/search-fda-guidance-documents/pediatric-information-x-ray-imaging-device-premarket-notifications (Accessed July 12, 2022).

[7] Smart Noise Cancellation Processing: Providing a New Level of Clarity in Digital Radiography and a Foundation to Reduce Dose. https://www.carestream.com/blog/wp-content/uploads/2022/05/white_paper_smart_noise_cancellation_low_dose_2000299_202203_ltr_en_2.pdf (Accessed Jun 15, 2022).

[8] Tugwell-Allsup JR, Morris RW, Thomas K, Hibbs R, England A. "Neonatal digital chest radiography – should we be using additional copper filtration?," Br J Radiol. February 1, 2022; 95(1130):20211026. doi: 10.1259/bjr.20211026. Epub December 14, 2021. PMID: 34797726; PMCID: PMC8822573.

[9] Tapiovaara M, Siiskonen T. PCXMC, A PC-based Monte Carlo program for calculating patient doses in medical X-ray examinations (2nd Ed.). http://ebookbrowse.com/pcxmc-20-documentation-v2-pdf-d144174950. (Accessed November 15, 2012).

[10] Schäfer S.B., Papst S., Fiebich M., et al. "Modification of chest radiography exposure parameters using a neonatal chest phantom," Pediatric Radiol. 50(1),(2020), 28-37.

[11] American Society of Radiologic Technologists. Best Practices in Digital Radiography. (2019). https://www.asrt.org/docs/default-source/research/whitepapers/asrt12_bstpracdigradwhp_final.pdf?sfvrsn=743d0370_16 (Accessed June 28, 2022).

[12] International Standard IEC 62494-1 (2008) Medical electrical equipment – exposure index of digital X-ray imaging systems – Part 1: definitions and requirements for general radiography. International Electrotechnical Commission, ISBN 2-8318-9944-3.

[13] Seibert J.A., Morin R.L., "The standardized exposure index for digital radiography; an opportunity for optimization of radiation dose to the pediatric population," Pediatric. Radiol. 41(5), (2011), 573-581.

[14] https://youtu.be/4AS05QuGWd8 (Accessed July 13, 2022).

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