Physics Behind The Phantom
Volume 2

The Neonatal Chest Phantom

Gammex Inc. has developed the new Neonatal Chest Phantom, a unique, anthropomorphic phantom designed for use in quality assurance of computed and digital radiography systems. To evaluate the significance of this product, it is instructive to look at the industry's trend toward wider use of computed radiography, along with its benefits, limitations and special requirements, especially as computed radiography relates to neonatal chest imaging, image quality and patient exposure to radiation.

The Trend to Computed Radiography

Traditional x-ray studies use screen-film radiography (SFR) to irradiate an intensifying screen and film in a cassette. When irradiated, the screen emits visible light, which then exposes the film. The exposed film is chemically processed to display the image.

Over the past 20 years, digital x-ray imaging, in the form of computed radiography (CR), has been increasingly used in place of traditional screen-film radiography. CR replaces the screen/film combination with a photostimulable phosphor plate that retains a latent image after irradiation. After exposure, the plate is scanned (stimulated) with a laser to convert the latent image to light. The light is then digitized and processed into a digital image which is prepared for display. Because the image is digital, it may be displayed on a cathode ray tube (CRT) or flat-panel LCD, printed to film, or stored on magnetic media for later retrieval. Other digital radiographic systems exist which use different detectors and signal read-out processes

There are many reasons for the trend to computed radiography:

- Digital images are identically duplicated, so that everyone views an "original." This eliminates the possibility of loss of "original" films as they're transferred between departments, and helps ensure secure recordkeeping for the hospital.

- Digital images can be widely distributed and displayed, making them available anywhere and at any time using PACs or teleradiology systems. This provides a huge advantage for clinics and small centers, allowing them to manage the patient close to home, while having a major medical center read the films.

- Film storage costs are reduced dramatically, and imaging centers don't need to maintain multiple screen/film combinations in order to be considered "state-of-the-art" or competitive.

- Finally, CR's technical superiority allows dose reduction while maintaining excellent image quality — both by eliminating retakes, and by virtue of the system's high sensitivity to x-ray.

Requirements and limitations of screen/film radiography

In SFR the film acts as both receptor and display device. The resolution and contrast of the final image is limited by the screen/film characteristics. The exposure required to create an image is determined by the speed and noise characteristics of the screen and film. The image quality is further affected by such film characteristics as the H&D curve, the screen speed and the film grain — all of which are fixed once the screen/film combination has been selected. Finally, the total latitude of the SFR system is only around two orders of magnitude, while the information potentially available in the patient may cover three or four orders of magnitude.

Because the requirements for good image quality for bone imaging, for example, are significantly different from those for good chest image quality, different screen/film systems should be used. For bone imaging, high-contrast, high-resolution, slow-speed screen/film combinations yield the best results. An optimal chest image calls for long-latitude, high-detail, fast-speed screen/film combinations.

Over the years, many screen/film systems have been developed to allow radiographers to optimize their imaging, but most facilities limit the number of screen/film combinations to one or two as a means of avoiding errors and simplifying ordering, storage and processing requirements.

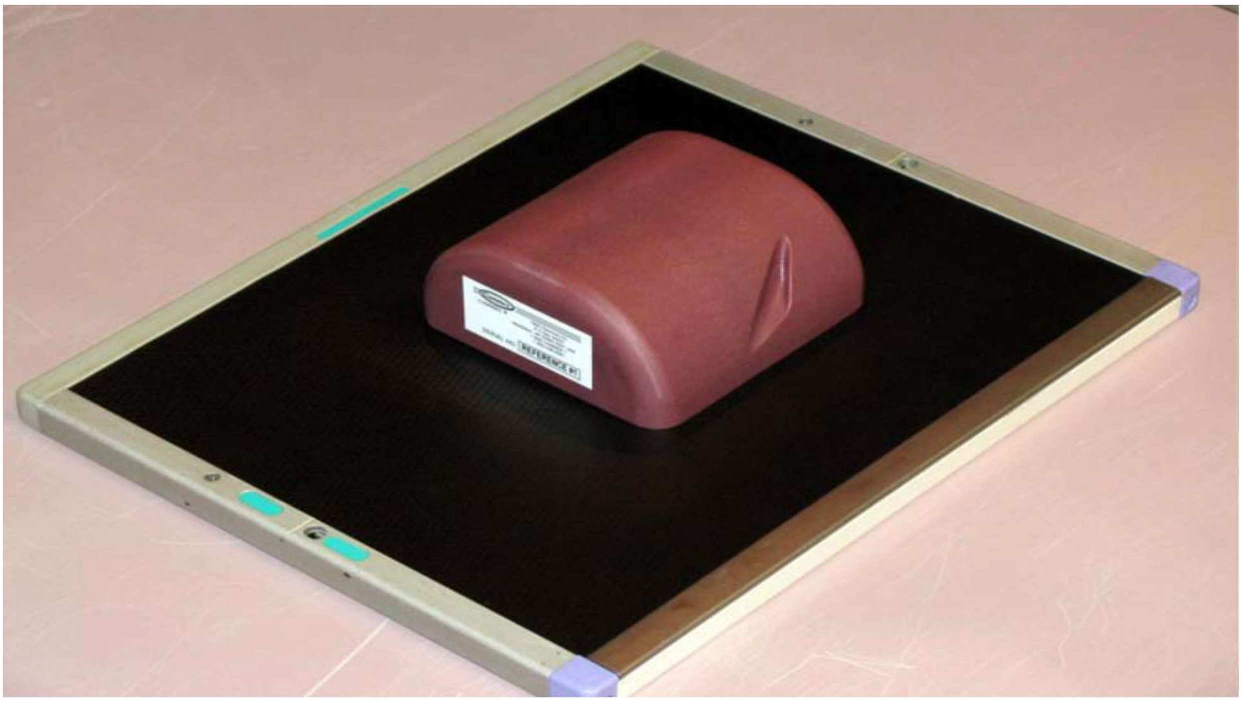
CR provides more information, more simply and safely

CR, on the other hand, is able to handle all imaging with a single linear detector with a dynamic range of over four orders of magnitude. This wide dynamic range permits all the information in the patient to be captured. Because the detector is decoupled from the display, over- and under-exposure of a radiograph are virtually eliminated by digitally moving the data into a useful display range. Low-dose radiographs offer image quality limited only by the noise levels acceptable to the radiologist. Overexposure is limited only by patient dose considerations.

Resolution and contrast requirements are handled by image processing. CR systems first make an intelligent selection of the data comprising the anatomy of interest and apply spatial frequency and contrast enhancements appropriate to the diagnostic task. Thus, high spatial frequencies and short to mid-latitude would be applied to bone imaging, for example, while medium to high frequencies and long latitude would be applied to chests. In addition, post-processing can be applied to modify the resolution up to the pixel size limitation and contrast to the viewer's preference.

All of the features of CR noted above have important economic implications. By eliminating under- and over-exposure the retake rate is reduced, saving film and technologist time. By eliminating the need for more than one screen/film system, the department saves supply, storage and administrative costs. But probably most important, the introduction of CR has made the all-digital radiology department possible.

Even today, over 60% of the radiology workload is plain film radiographs. Until the advent of CR, investment in a large scale PACS and teleradiology venture could not be justified for CT and MRI alone. The ability to directly capture digital radiographs for archiving and distribution is changing the character of the radiology department.



With CR, anatomic detail is relevant for image optimization

Most CR systems use a type of histogram analysis to process the image data. In order to create the best scaling and processing of the image data, computed radiography systems must have *a priori* knowledge of the anatomy being radiographed. The histogram is analyzed according to characteristics which are expected for that anatomy. This analysis directly impacts everything from auto-ranging of the data to appropriate spatial frequency processing.
For example, using the same x-ray system and the same technique factors as for screen/film images, the CR system will not give the same image quality for a humerus in a cast and out of a cast unless the image-processing algorithm is also properly selected.

It is this coupling of image processing to anatomical reference which makes image quality assessment of a CR image impossible to do completely with so-called "technical phantoms." This is because the algorithms are built from a set of histogram characteristics determined empirically from actual radiographs. If an abdomen is processed as a skull, for example, it would have improper density and little to no contrast — even though there may be nothing wrong with any part of the system.

The need for a new type of test tool is clear. Some technical phantoms do exist now, such as the Leeds phantom. These phantoms consist of various configurations of well-defined test objects in a uniform background, and can only be used with test protocols which vary dramatically from clinical imaging protocols.

Thus, manufacturers face major challenges in optimizing system parameters for particular user tasks, and service and support engineers find trouble-shooting in the field problematic because there are no tools which allow system characterization and performance optimization.

Similarly customers are faced with related challenges when acquiring and establishing quality assurance for CR systems. They must evaluate products and vendors, decide which configurations produce satisfactory results and determine the “operating point” for their technical protocols. Upon installation of new products or during upgrades, acceptance testing is required to ensure that the product meets specifications or produces images consistent with those of the older releases. This is an ongoing process, as vendors frequently introduce new hardware models and upgrade software.

Once digital systems are in operation, routine quality control (QC) procedures must be established just as in all other areas of radiology. For routine compliance, QC procedures must be convenient and give unambiguous information about the state of the digital system. It is reasonable to expect that ACR and/ or the CDRH will be imposing quality assurance requirements on computed radiography as more departments convert totally or partially to digital imaging. This is especially likely when one considers the potential for patient exposure to increase without detection in the clinical images.

In order for a phantom image to successfully demonstrate acceptable image quality using CR, it must be able to present histograms to the system which simulate the histogram of the anatomy being imaged. Test tools which have no physical similarities to a known anatomy cannot be used to test the system image quality performance for CR. However, with the availability of computers to do the analysis, there is a growing demand for more sophisticated tests of digital radiographic system performance. The addition of a technical component to extend the sophistication of the QA testing to the level necessary for digital radiography complements and completes the total product.

Quality control of CR is especially important in pediatric imaging

Because of their high sensitivity and extended dynamic range, digital receptors open the way for reduced-dose radiography. This is of major importance for pediatrics. Because children are still developing, their tissues are in a state of rapid differentiation and growth. This is known to put children at high risk of cancers from all carcinogens, including radiation. In two recent studies it was shown that radiation to children, even at diagnostic imaging levels, doubles the risk of childhood leukemia. The need to manage and reduce dosage is a very real concern for pediatric radiology departments and children's hospitals.

Ironically, the very features which make CR a choice of pediatric hospitals is also responsible for added radiation risk. Because the final image is now insensitive to over- and under-exposure, it is possible to operate with equipment that is out of calibration. In fact, it has been shown that 43% of the children's CR images are over-exposed. This is a particular concern for neonatal ICU's where a patient is typically radiographed two to three times daily to monitor intubations and lung function.

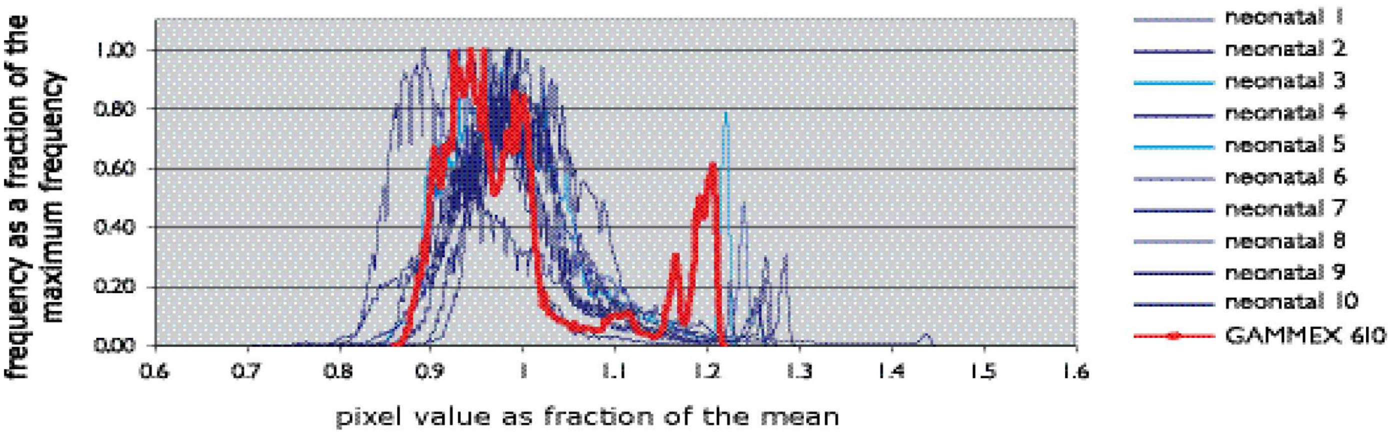
Finally, it has long been known that the most difficult anatomy to image is the neonate. The small size, low subject contrast, and difficult radiographic environment (the neonatal isolette for example) create the greatest challenge to all imaging, and especially CR. Detection of one pathology, the pneumothorax, challenges every known system parameter (contrast, resolution, image processing, appropriate histogram selection, etc.). Additionally, hyaline membrane disease, a characteristic finding in premature infants, is often mimicked by the characteristic mottle of the CR plates at low dose.

The availability of a quality control phantom for CR which can predict a system's ability to image the neonatal chest would be a definitive test tool for any CR system.

The Gammex 610 Neonatal Chest Phantom addresses image quality and patient exposure concerns

The new Gammex 610 Neonatal Chest Phantom is designed for routine quality assurance of computed and digital radiography systems. The Gammex 610 is a unique anthropomorphic neonatal phantom that mimics a 1-2 Kg neonate in its transmission characteristics, histogram, physical size and structure. Because the phantom replicates both the anatomic structure and the tissue attenuation characteristics of a real neonate, the phantom can be imaged using clinical protocols, resulting in a test of the entire imaging chain including image-processing parameters.

Normalized Histogram Comparison for 10 Normal Neonates and Phantom



The Gammex 610 answers a recognized need by both international and national standards groups such as IPEM and AAPM for a comprehensive quality assurance program for computed and digital radiography by addressing the two major concerns of patient exposure and image quality.

Patient exposure is a concern because computed and digital radiographic equipment will scale the overexposed images to the proper optical density. The result, often referred to as “dose creep,” is especially relevant in pediatric imaging where some patients are radiographed several times per day. The Gammex 610 phantom is specially suited as a tool for establishing the lowest possible exposure level that still maintains diagnostic image quality.

Evaluation of image quality is complicated by the way in which computed and digital radiographic systems use *a priori* knowledge of the anatomy being radiographed to process and display the image. Image quality can be degraded through improper parameter selection. Such effects on image quality can be assessed only by using a phantom that replicates the human anatomy. The Gammex 610 also contains clinically relevant image quality challenges for resolution and noise in the form of a lung with simulated pneumothorax with pleural thickening, and a lung with simulated hyaline membrane disease.

Gammex 610 Specifications:

Size	Approx. 100mm x 100mm x 54mm
Weight	Approx. 500 grams
Composition	Air, (Tissue Equivalent Materials) Muscle, Normal Lung, Hyaline Membrane Lung, Bone

Lungs Included

#1 Left – Hyaline Membrane Disease: Pneumothorax
#2 Right – Hyaline Membrane Disease Texture: No Pneumothorax
#3 Left – Normal Texture: Pneumothorax
#4 Right – Normal Texture: No Pneumothorax

Gammex 610 Neonatal Chest Phantom comes with a custom carrying case.