The Novato Community Hospital in California, USA, recently switched to digital radiography. CR readers have now been installed across the hospital, from the emergency room and operating room area to the outpatient center and the radiology department itself. Digitization has solved a major bottleneck in the department’s workflow. In the past, personnel often shared a single workstation for patient examination, cassette labeling and processing. Now, the workflow is better distributed by physically separating these functions over a number of workstations in different locations.

The physician’s diagnostic accuracy has also increased, as correctly processed digital images make it easier to visualize and identify lesions. Diagnostic accuracy in radiographic interpretation can be seen as dependent on optimum image quality, and an alert and experienced radiologist. Even the most experienced radiologist can become tired of interpreting large batches of difficult-to-read images, so ready-to-read radiographs with optimized contrast in all areas are not just a luxury: they can play a vital role in maintaining diagnostic accuracy.

Optimum image quality is determined by several factors:
• optimal dynamic range
• noise reduction
• edge enhancement
• normalized gray scale latitude over the whole image area.

Many publications have discussed the variables and nuances of computed radiography image quality using conventional measures such as image matrix and gray scale bit depth [1-8]. However, to make a clinically significant impact on diagnostic accuracy for the radiologist, the “conspicuity” or “obviousness” of the finding needs to be addressed. This can be accomplished using advanced postprocessing techniques which fine-tune the dynamic range and edge enhancement of the CR image. In addition, these algorithms can provide for appropriate noise reduction and, potentially, for a region-specific histogram adjustment. When the postprocessing algorithm is correctly set, optimized read-ready images can be more readily interpreted by trained radiologists, helping them to find lesions with higher accuracy and confidence.

In the Novato Community Hospital, the images are processed using the Unified Image Quality Enhancement (UNIQUE) post-processing algorithm. This has been a major contributing factor to the increased efficiency in the department. Most of the X-ray examinations in the hospital are portable chest X-rays. These images often have a wide range of exposure between the top and the bottom of the lungs. UNIQUE harmonizes contrast levels over the whole image area, enhancing faint contrast and adapting the parameters in each region of the image to provide a wealth of detail with a wide dynamic range.

One of the major advantages of UNIQUE is that it shows abnormalities in the portable lung studies with greater conspicuity. Lesions can be seen in the lung apex as well as behind the shadow of the heart. This accounts for the most significant clinical improvements. UNIQUE also offers advantages at the very periphery of the lungs, where the rib shadows overlap. Here it is possible to detect pleural nodules that would otherwise be obscured.

Another advantage is the improved visibility of catheters, tubes and pacemaker wires. Here it is vital to show their positions accurately, while still being able to see the lungs. This can be a particular problem with nasal gastric tubes, because the tip of the tube lies in the stomach, which is at the bottom of the image and, hence in the most underexposed region.

Examples of improved conspicuity obtained with the UNIQUE algorithm are presented below, and the impact that this improvement has on clinical outcome is discussed.
Materials
Most of the images presented in this article were obtained using a Philips Bucky Diagnost system with standard kVp/mAs settings for the various body parts. Additional images were obtained at the bedside or in the ICU using a Philips mobile unit. The computed radiography cassettes were read in a Philips PCR AC5000 CR reader, and the postprocessing algorithms were applied at a technologist’s QC workstation (Philips EasyVision). All images were displayed on a radiologist’s softcopy display station using a SINOMED gray scale 1.6 K CRT.

Methods
The computed radiography image was postprocessed twice: once with a basic conventional processing algorithm used by many CR installations, and once with the “UNIQUE” advanced postprocessing method.

UNIQUE offers universal multiresolution image processing for all Philips digital radiography systems. It displays the enhanced images according to pre-defined user settings without the need for interaction, automatically compensating for large variations in radiographic density. A typical example is chest imaging, where the mediastinum and the thoracic spine absorb strongly, while the lungs are almost X-ray transparent. This means strong contrast in parts of the image (spine) juxtaposed with areas of weak contrast (lungs). In hard- or softcopy displays of such images the large variations have to be reproduced without clipping, while subtle details such as lung nodules must remain visible.

In digital radiography, these conflicting requirements can be reconciled by digital processing even before the image is displayed. Digital image processing makes it possible to decouple the image acquisition and image display stages. These methods can then be used to enhance detail contrast while maintaining the latitude in the displayed image.

Digital image processing has developed significantly over the last 20 years. In the 1980’s, unsharp masking with single-kernel enhancement produced crisp but rather artificial-looking images. This was then superseded by the two-kernel enhancement of Dynamic Range Reconstruction (DRR), which produced clearer and more realistic images, but was prone to produce edge artifacts. UNIQUE represents the latest stage in this development, with multiresolution, nonlinear processing, producing improved images with fewer artifacts.

UNIQUE reconciles the conflict between contrast and resolution by using image processing based on three key characteristics: multi-resolution, nonlinear and universal. The multiresolution filters decompose the image into a number of bandpass images, each containing the information for a specific detail size. This type of image filter allows much greater flexibility in adapting the processing to the anatomical region, the type of detector and even the clinical question.

Because UNIQUE processing is inherently nonlinear, the relative enhancement is stronger for low-contrast details than for the easily visible high-contrast structures. This improves the visibility of subtle details and significantly reduces edge artifacts.

The three key characteristics of UNIQUE processing are outlined below.

Multiresolution
In the multiresolution phase an image is broken down into several frequency channels, with each channel representing structures of different size and different levels of contrast.

Nonlinear
Each channel is then processed separately, depending on the requirements. Under- and over-penetrated areas are optimized accordingly. Once processed, the channels are then combined again to produce the overall optimized image for display. For example as a result subtle details are enhanced, without generating edge artifacts in other parts of the image.

Universal
No matter which digital X-ray modality is used, the parameters for all systems and detectors are the same, making the handling easy and intuitive across all digital systems.

The net result of UNIQUE processing is “harmonized contrast”:
• good detail visibility in under- and over-penetrated areas
• latitude and detail contrast rendition can be adjusted independently
• detail contrast is independent of local density/brightness
• multiresolution representation suppresses most artifacts and noise amplification.
• most beneficial for images with inherently large latitudes, e.g. chest, skull or lateral spine.

Results
In many cases, the advanced postprocessing method has made it easier to detect an important X-ray finding. A selection of these cases is presented below.
Case 1: Cervical spine trauma
Figure 1a shows conventional processing of a lateral cervical spine radiograph obtained as part of a screening lateral spine study with a mobile unit in a patient with motor vehicle accident trauma. Note that in Figure 1a the seventh cervical vertebra (C7) is barely visible, making it difficult to detect any pathology. In contrast, the image obtained with UNIQUE postprocessing (Figure 1b) shows a conspicuous fracture at C7. The improved conspicuity is the result of UNIQUE postprocessing, which adjusts the dynamic range in the lower cervical spine, while maintaining correct contrast and brightness in the upper cervical spine.

Case 2: Mediastinum structures
Figure 2a shows an air-filled structure behind the heart (curved arrow). With UNIQUE postprocessing (Figure 2b), both the left and right borders of the structure are well seen, making the diagnosis of hiatal hernia more obvious (straight arrows). The line tip is also easier to see.

Case 3: Spine structures
Figure 3a shows the spine as “just visualizable”; however, the wider dynamic range in the UNIQUE image (Figure 3b) shows lung contrast just as well as in Figure 3a, yet the spine structures can now be better assessed and the presence of vertebroplasty cement (arrows) is now obvious.

Case 4: Chest with incidental finding of free air
These images were obtained on a mobile X-ray system in the ICU. Figure 4a shows clear lungs; however, improved visualization using UNIQUE processing (Figure 4b) shows the presence of free air below the diaphragm. This is a critical finding which should not be missed.

Case 5: Lung nodule conspicuity
Figure 5a shows a lung nodule almost concealed between the 2nd and 3rd ribs on the right. The finding is easier to see on the UNIQUE image (arrows in Figure 5b). CT scan correlate (Figure 5c) shows the presence of an adenocarcinoma, confirmed histologically.

Case 6: Monitoring lines visibility
Figure 6a shows diffuse air space disease. The monitoring lines can also be seen, but only after performing manual window-level adjustments. In Figure 6b, the lung air space disease can be well assessed at the same time, while the monitoring lines can also be easily identified, with no additional window-level settings.

The ability to present a “read ready” image in which both lung disease and line positions can be quickly assessed without continually performing specific window-level adjustments is especially useful to critical care personnel, who may be viewing the image with a standard PC monitor on a web-based viewing application at the bedside.

Case 7: Emphysematous lungs
Figure 7a shows severe emphysema in a cachectic patient. This situation poses particular imaging challenges, since the center and window levels must be carefully chosen when attempting to image what, from the viewpoint of radiation physics, can be compared to “radiographing a balloon”. In Figure 7b, the lung parenchyma is well seen, and the need for end user adjustments to the center and window levels is minimized.

Case 8: Pneumonia with important findings hidden behind the left heart border
Figure 8a displays an infiltrate behind the heart which is difficult to perceive. In the UNIQUE image (Figure 8b), the infiltrate can be more readily seen with greater conspicuity. The CT scan (Figure 8c) confirms the retrocardiac infiltrate.

Case 9: Peripheral lung nodule conspicuity
Detecting a small peripheral lung nodule has always posed a challenge for interpreting radiologists. The observer usually needs to employ more than one window-level setting adjustment to appreciate a peripheral nodule such as that shown in Figure 9a (curved arrow). However, the nodule is well demonstrated in the UNIQUE image (Figure 9b) with no additional window-level adjustments.

Both the lung center and the periphery are optimally displayed on the UNIQUE image. The clinical importance of presenting a “read ready” image where nodules in both the periphery and the lung center and the lung bases can be easily visualized on the same image must be emphasized.

The reading radiologist will not know, before the fact, if the nodule that needs to be detected is located peripherally or centrally. This “read ready in all anatomic areas” is a concept that is critical to optimizing lung lesion detection on plain X-ray.

Case 10: Peripheral chest findings better seen (bronchiolitis obliterans)
In Figure 10a, the lung opacities appear non-specific, with some question of underlying effusion. The parenchymal lung disease pattern of bronchiolitis obliterans is better appreciated in the UNIQUE image (Figure 10b).
Bronchiolitis obliterans is confirmed by the CT scan (Figure 10c).

*Case 11: Spontaneous pneumothorax*

Figure 11a shows a typical pneumothorax. The pneumothorax line is visible, but requires careful observation. The UNIQUE image (Figure 11b) shows the line with greater conspicuity.

**Discussion**

Several papers have focused discussion on traditional image quality measures such as image matrix and gray scale bit depth [1-7]. However, these two parameters are only the beginning. It is well known that proper adjustment of image window levels can provide an “acceptable” image, but such an image as assessed by comparison with film/screen...
techniques, and resembles a film/screen image in its overall appearance.

Early generation postprocessing involved this type of simple adjustment of the window-level settings, based on a histogram analysis of the image gray scale. A prescribed amount of edge enhancement (i.e. “unsharp masking”) was applied. Although this primitive technique has advantages over film/screen images, the conspicuity of lesions, as compared with film, was only minimally improved.
Advanced postprocessing algorithms provide for dynamic range adjustment based on region-specific histogram analysis. This sensitivity to region allows for better image gray scale adjustment in areas such as the upper abdomen in chest X-rays or the seventh vertebra in cervical spine X-ray. In addition, appropriate noise reduction and/or unsharp masking can be applied. The final product is a “read ready” image where the gray scale is optimized in both the heavily exposed areas (e.g. lung apex) and in the barely exposed areas (e.g. retrocardiac lung and upper abdomen). It is through this gray scale adjustment that lesions can become more obvious and conspicuous, even though they may be located in areas that are classically hidden or obscured because of the density of overlying structures.

A well-known advantage of a soft-copy read over a film viewbox read is that areas of interest which appear too dark on the image can be manually adjusted; however, there is a problem with this dependence on manual adjustment of an “area of interest.”

The problem stems from the fact that the radiologist has no a priori knowledge of which part of the X-ray contains the critical finding. In some cases, the finding will be in the lightest part of the image and, in other cases, the finding will be in the darkest part of the image.
It is here that the advanced post-processing techniques step up to facilitate improvement in the conspicuity and detectability of a lesion. The UNIQUE postprocessed images have a more normalized appearance, so that it is possible to see nodules in the lung apex, yet, at the same time, the bones in the clavicle and shoulder joint can also be assessed. This type of normalized image represents the ultimate form of “read ready” image in which the gray scale is optimized in several regions of the image.

**Conclusion**

Several case examples are shown which display the improvement in lesion conspicuity using advanced postprocessing techniques. Employment of this type of processing moves the definition of “read-ready” image to a whole new level, where lesions can be detected in both “very dark” and “very bright” regions of the computed radiograph.
References


