White Paper

Enhanced Conspicuity with DuraLight Nova™

What's inside?

- Luminance limits the size of what we can see
- How higher brightness increases contrast
- Ambient light and working conditions
- Clinical advantage of more light and contrast

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ABSTRACT

Breast screening is challenging partly because of limitations in our ability to see small and subtle objects. With DuraLight Nova, a softcopy display offers the same luminance as traditional film. This luminance increases visualization of subtle (low contrast) and small breast structures.

Ambient light can be increased when using DuraLight Nova, reducing radiologist fatigue and providing a more comfortable environment. With twice the luminance of PACS displays, DuraLight Nova increases the number of Just Noticeable Differences (JNDs) and the apparent contrast of the clinical images. In addition, micro-calcifications are more conspicuous, and the appearance of both fatty and dense breast tissue is improved. People work more quickly with higher luminance, performing less image manipulation and interpreting each image more rapidly.

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INTRODUCTION

Breast imaging allows us to either confirm a woman's health or detect and characterize disease. It is challenging for a number of reasons. First, screening for breast cancer involves many healthy women with a wide variety of breast appearances. Mixed into this healthy population is a small population with early-stage breast cancer. A large expenditure of skilled radiologist time is required to carefully examine each case to determine health or disease. Most of the time is spent searching for evidence of disease in healthy women. Second, early-stage breast cancer is subtle when it is present. The disturbed breast structures and micro-calcifications are quite small, and the contrast between adjacent tissues can be very low, whether imaged with X-ray, ultrasound, or MRI.

This white paper explores how the Barco technology embodied in the DuraLight Nova backlight increases clinical image contrast and the conspicuity of small structures in the breast.

People have been working for decades on the technology to acquire and display breast images. Let us first consider X-ray film:

- To increase the contrast of subtle variations in tissue density, the emulsion has very broad latitude.
- The grain size of the silver in the emission is very fine, allowing very small objects to be distinguished.
- The light box used to illuminate the developed film is very bright. When shining through the least exposed X-ray emulsion, the luminance is about 1000 nit.
- Resolution is 12-14 line pairs/mm, corresponding to ~25 microns.

Now, let's consider digital acquisition and softcopy:

- Digital detectors have a resolution of 50 µ - 100 µ. While this is not as fine as some film, clinical details are visible. What is important is to make 50 µ - 100 µ details conspicuous.
- It is possible to process the area of the image at the skin line to compensate for the thinness of the tissue.
- Between 2002-2008, display luminance evolved from 350 cd/m^2 to 600 cd/m^2. Now in 2011, 1000 cd/m^2 is possible.

No two technologies are alike, and some aspects of film had to be compromised to move to softcopy display of mammography images on CRT and LCD displays. Despite some compromises, softcopy mammography has proved to be at least as good as film, and it can be better still.

Studies of the cancers from the ACRIN DMIST trial found that, in women with dense breasts, significantly better diagnostic accuracy of digital mammography, as compared

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with screen-film mammography, was most likely attributable to differences in *image contrast* due primarily to differences in the display and acquisition characteristics (Pisano *et al.*, 2009). Assuming that a site is already doing everything possible to optimize acquisition characteristics, this paper analyzes how to get *more clinical image contrast by optimizing display characteristics*.

The following display characteristics affect clinical image contrast:
- Introduced noise
- Spatial resolution
- Response time
- Display brightness and contrast

The advantages of noise reduction and spatial resolution for mammographic detection have been reported previously (Bacher *et al.*, 2006), but that study specifically controlled the luminance of the various displays to focus on these parameters. Response time limitations have been essentially overcome by Barco's RapidFrame™ technology. The advantages that RapidFrame brings to moving images is covered in a companion white paper (Multi-modality breast imaging using RapidFrame™). In this present paper, we explore the powerful benefits of increased display brightness and contrast made possible by DuraLight Nova.

Barco's DuraLight Nova technology builds on previous Barco technologies. The original DuraLight technology began in the air traffic control division, where long lifetime and an extremely low failure rate were essential. By combining this technology with some elements of the Per Pixel Uniformity technology, it became possible to build a much brighter display with better contrast and better uniformity than ever before.

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1. How Luminance affects what we can see

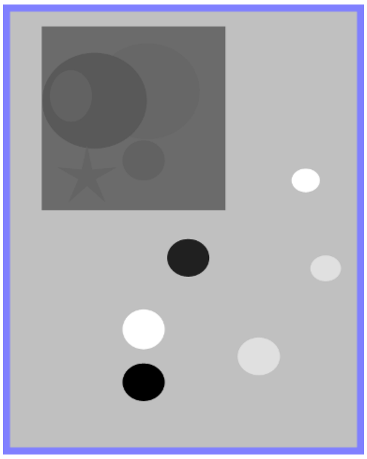
Long before modern PACS displays were imagined, research at the University of Utrecht was conducted on the relationships between Contrast, Luminance, and Spatial Resolution – three factors that interact as we detect something with our eyes.

Two important relationships were reported in 1967 (Van Nes & Bouman, 1967):

1. The *contrast* needed to detect an object is inversely proportional to the square root of the luminance.
2. The *luminance* needed to detect an object increases exponentially as the object's size diminishes.

The first relationship, $thresholdObjectContrast \propto \frac{1}{\sqrt{luminance}}$ indicates that, with twice the luminance:

- We can see an object with contrast 0.707 * (the contrast that would have been required).
- An object that was undetectable before with ¾ of the required contrast *will now be detectable.*



That's a nice finding: it applies to the entire image, over a broad range of object sizes and contrasts. Consider the upper left area of the image on the right. Even though the image in this example area is presented with only 8% of the overall contrast depth, the eye will adapt to this area and then be able to detect and characterize very low-contrast details. When you first look at this image, you see a dark square with perhaps two or three circles in it. As you stare at the image for a few seconds, additional objects become visible. Likewise, in the case of a bright mammography display, a bright or dark region of interest will rapidly yield more information as attention dwells on it, even though the display's contrast range exceeds what the human eye can see at any one time. In the case of a display at lower brightness, it's hard to see more than what is already detectable with the eye at first glance. (Experiment with this phenomenon on a laptop display, adjusting the brightness to experience this effect.)

The second relationship, $luminance \propto \exp(\frac{cycles}{degree})$, is about visual acuity – the ability to resolve fine image details. As objects become smaller, they must be very well illuminated to be seen. Compare using a brighter light to read fine print – even though the print on the page does not gain or lose contrast, our acuity increases.

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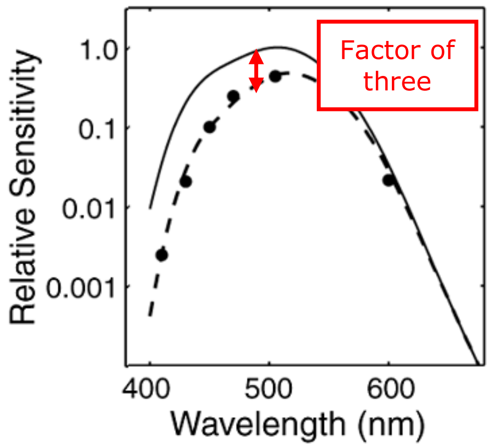
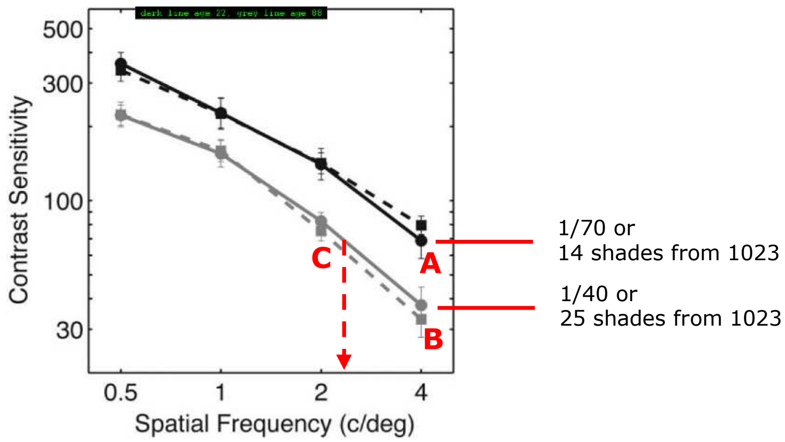
Rose describes how our eye is limited by the finite size of the rods and cones, but also by the number of light quanta that fall on a small area over a period of ~0.2 sec (Rose, 1948). Because our eye has its own internal noise signals, the light we see needs to be noticeably greater than this. So, if we increase the number of photons coming from the medical image, they will be more distinguishable from the internal eye-noise. An additional limitation is the efficiency of our eye's optics: there is a certain amount of blurring and absorption. Some of the light fails to reach the correct area of our retina, and that light lands on adjacent areas, adding to the noise. This has been measured for people of different ages, and it is not surprising that our eyes do not improve with age. The typical loss of light transmission because of increased absorption is shown in the chart on the right, which compares someone 73 years old to when they were 27 (Hardy *et al.*, 2005).



Similarly, the chart below illustrates how, as sensitivity to contrast for shorter wavelengths decreases, the ability to discern small objects decreases (comparing persons of 22 and 88 years of age). Point A indicates that the 22 year-old can discern 4 cycle/degree objects that are about 1/70 different from the background. With the same light, the older eye is closer to point C, where objects that small cannot be detected, but larger objects are still visible. *Van Nes and Bouman* tell us that equalizing the difference in visual acuity requires either more luminance or more contrast or bigger images.



To counteract this loss, we could increase the contrast to 1/40. This can be done by:

- Adjusting window level
- Higher dose
- More light

With dose and light, the factor is the square of the required contrast factor:

$\left(\frac{1/40}{1/70}\right)^2 = (1.75)^2 = 3.06$, which matches the loss in acuity in our example. Adding more light to the display is preferable to raising the dose, and it is also less work for the radiologist than adjusting the window and level.

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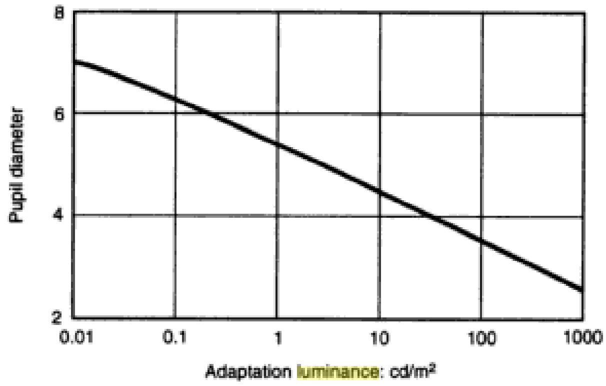
One of the ways increased luminance increases visual acuity is by decreasing the diameter of the pupil. Pupil diameter is regulated by a third type of photoreceptor in our eye. The two commonly known photoreceptors are: rods (very sensitive receptors, used especially for night vision and peripheral vision), and cones (responsible for color vision).

The third type of photoreceptor – ipRGC – uses the pigment melanopsin (Berman, 2008). Not identified until 2002, this photoreceptor was discovered as researchers sought to explain the light-driven spectral response of melatonin, the hormone that regulates circadian rhythms. As it is most sensitive to light at 482 nm, our pupil's diameter is most affected by blue light.



DuraLight Nova aids the radiologist with the help of this ipRGC receptor. The benefits of more luminance include:

- More acuity with a small pupil opening
- Shorter accommodation time – the eye does not need to adapt to its largest pupil opening

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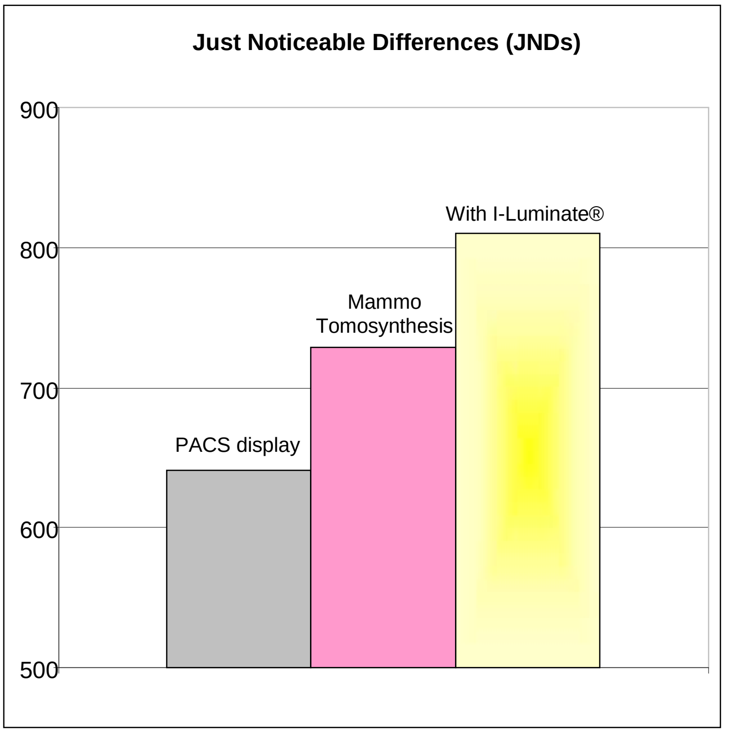
2. How much brighter is DuraLight Nova?

DuraLight Nova is capable of delivering a calibrated luminance of 1000 cd/m^2 throughout the entire useful lifetime (5-7 years) required for a mammography display. This is twice as bright as the 500 cd/m^2 typical of PACS displays. In addition to being extra bright and having a long life, DuraLight Nova has some more special features:

- The I-Luminate™ button allows the display to be driven temporarily to double brightness (up to 2000 cd/m^2). This even higher luminance is also calibrated to the DICOM standard.
- Film-mode allows a reference film to be illuminated by the powerful backlight. The illuminated area is 18x24cm or 24x30cm to accommodate standard mammography films.
- Uniform illumination is provided by a combination of Per Pixel Uniformity (PPU)[1] and DuraLight Nova optics[2].
- A Blue base tint is provided by default. This blue color has generally been favored for mammography work since it was introduced in 1934 by Kodak. It provides better visual acuity (Rose, 1948) and most people find it less fatiguing to work with. Clear base tint is also an available option, which can be useful for matching the display tint to a body of existing PACS displays.

One way to compare the contrast and brightness of calibrated medical displays is to count the Just-Noticeable Differences (JNDs). Barten has measured steps that represent the minimum luminance difference the average observer can discern (Barten, 1992). Based on the minimum and maximum luminance, a display can present more or fewer of these steps or JNDs. This is the apparent contrast. In the adjacent chart, the Barco's Mammo Tomosynthesis display is shown as it is driven with the DuraLight Nova. Also shown for comparison is a typical 5MP PACS display and the Barco display with the I-Luminate button pressed.



[1] Per Pixel Uniformity uses US Patent 7,639,849
[2] DuraLight Nova uses EU Patent 1,650,730

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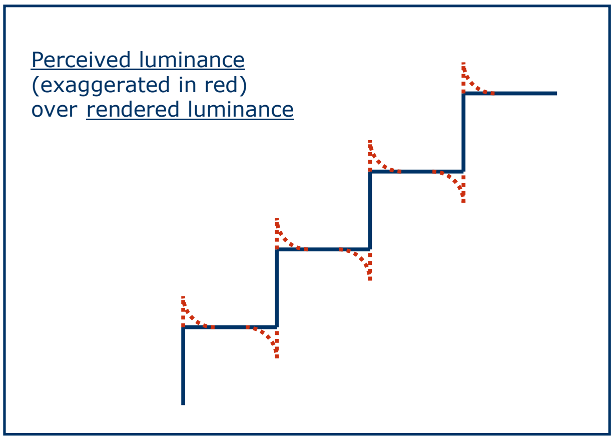
When there is enough luminance to allow the eye to see the difference between an object of interest and the background, our eyes are able to accentuate the difference (Mach, 1865). This Mach-band effect is illustrated in the image below. Each gray rectangle is a uniform shade. Yet, despite being composed of only one shade, because each rectangle is adjacent to another of a different shade, our eyes enhance the difference. Thus, it appears that the left side of each rectangle is darker than the right side of the same rectangle.



This effect is further explained with the chart at the right. Ideally, all images would be infinitely precise representations of the physical condition. It is, however, possible to represent most continuous phenomena with a digital scheme, using enough bits so that little information is lost. The question is always: how much is enough? From research conducted by Barten, it is clear that the human eye can discern objects with minute contrast, and 10 bits are required to represent the level of precision that the eye can discern over the luminance range provided by a modern medical display. To display medical images properly, we want to have enough luminance to be able to see subtle differences that really are in the image, and we want to have enough grayscale precision so that we do not introduce distracting quantization. Quantization introduces artifacts in medical images where the tissue density varies slightly over an area. This should appear as a continuous change in density, but the reduction in precision (to 8-bits, for example) introduces unnatural contours that are then enhanced by our eye. Maintaining 10-bits is sufficient to avoid this visible quantization effect.

DuraLight Nova raises the brightness and apparent contrast with a powerful uniform illumination.

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AMBIENT LIGHT IMPROVES WORKING CONDITIONS

When softcopy displays were rare in reading rooms, people found that some ambient light was helpful for ancillary tasks like reading charts and avoiding obstacles. Then, when early softcopy displays were introduced, they had much lower luminance than film on light boxes. As a result, the ambient room light reflected from the display obscured many of the darker parts of the image. To counteract this, reading rooms with softcopy displays were often plunged into darkness, illuminated only by the displays and light boxes in the room.

The eye accommodates to the prevalent light, which is partly from the display and partly from the ambient environment. If the ambient light is very dim, the eye must continually accommodate between the screen and the wall behind the screen. Total darkness is not recommended. (Siegel *et al.*, 2006). This accommodation requires some effort by the chemicals and muscles of the eye, leading to fatigue. DuraLight Nova makes it possible to use comfortable room lighting to minimize fatigue while preserving the contrast of the medical images.

Some advantages of light in the reading room:

- Paperwork is easier to read
- Keyboard and mouse are visible
- Radiologists experience less eye fatigue
- Cleaning staff can see without changing the lighting settings
- Compliance to standards for ambient light (e.g. DIN6856)

Ambient illuminance and display luminance can be monitored either manually or automatically. On Barco's Mammo Tomosynthesis 5MP display, both are done automatically. The ambient light sensor monitors the chosen room lighting and enables the QC manager to ensure that the levels are maintained over time. The I-Guard provides continuous adjustment and regular reporting of the display luminance.

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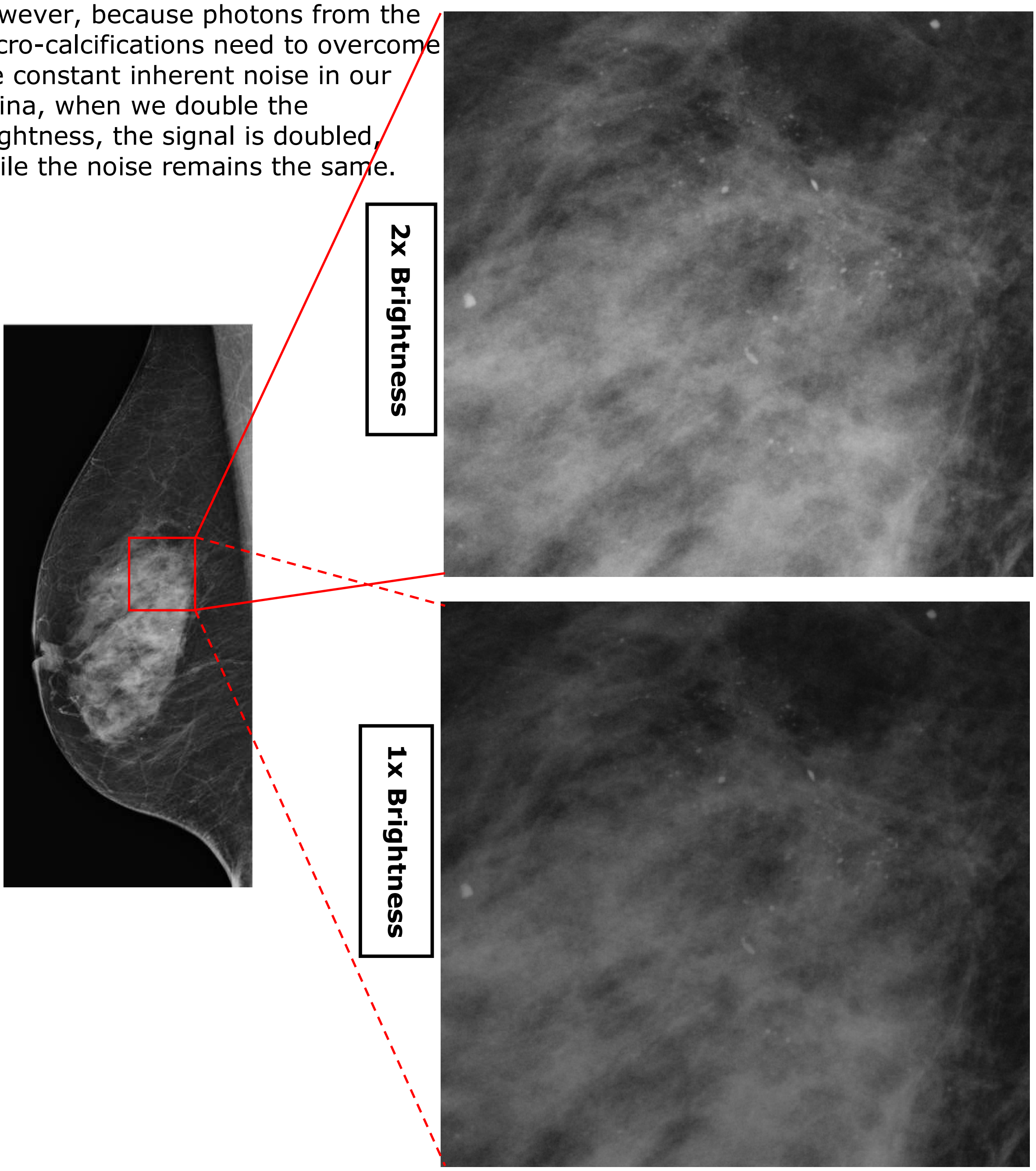
3. Examples in medical images

As micro-calcifications are projected onto a very small portion of our retina, they are easier to see when they are bright.
However, because photons from the micro-calcifications need to overcome the constant inherent noise in our retina, when we double the brightness, the signal is doubled, while the noise remains the same.



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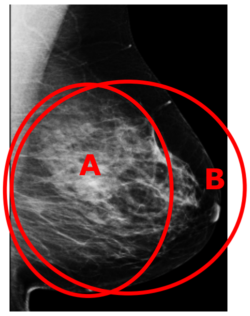
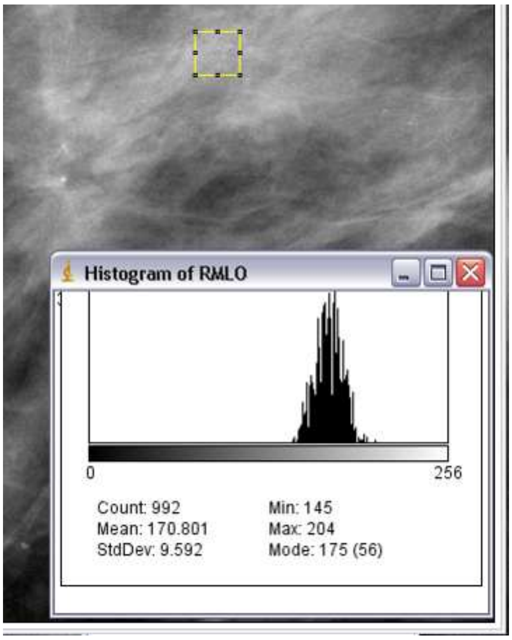
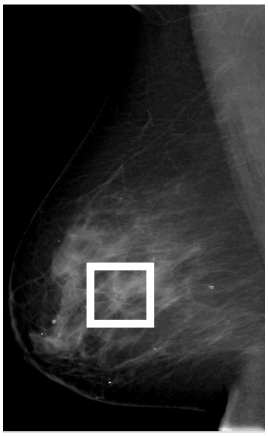
Areas of different tissue density have very different luminance levels. Broadly speaking, breast images have two different regions of tissue density: Region A is dense (bright), Region B is fatty (dark).



In dark image areas, the luminance is very low, so small details are invisible. Recall from section 2 that as luminance decreases the minimum size of detectable objects increases. This is why some viewing applications provide an inverted magnifying glass. Although individuals vary, most people are more limited by the brightness and contrast of small objects than they are by the pixel size of the display.

In brighter areas, there is a limited range of values, which results in poor contrast. Consider the sample dense image below, where less than a quarter of the range (see histogram) is used. It is in precisely such a dense area that small object conspicuity is needed. The limited contrast inhibits detection of small objects, but DuraLight Nova's higher luminance increases the necessary conspicuity.





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4. Financial Implications

Brighter displays enable radiologists to do their work more quickly. There are a couple of reasons for this: first of all, less image manipulation is required; and secondly, the time spent viewing a given image is shorter.

Image manipulation is necessary when the details in the image are not clear in the default presentation. In this case, if a certain part of the image is dark, it can be adjusted with W/L, and if the extent of the calcifications is unclear, the magnifying glass can be used. Because a brighter display clarifies the details of an image, the image manipulation tools are often not necessary.

It has long been a concern that screening work would take longer on digital displays than on film. Even after softcopy workflow has been optimized, it has been found that interpretation of individual FFDM images can take longer than film. One study performed with experienced radiologists at St. Luke's Hospital in Tokyo – comparing a high contrast digital display set to a brighter screen film system – found that interpretation was faster on the SF system. Reading the FFDM images took 1.2–1.8 times longer than reading the SFM images, regardless of the reader's level of experience or the similarity of the mammograms (Ishiyama *et al.*, 2009). In other tests performed with displays of different luminances, total viewing and decision dwell times were shorter with the higher-luminance displays, especially for true-negative decisions (Krupinski *et al.*, 1999).

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5. Clinical Implications

Contrast and luminance are both strongly correlated with the conspicuity of mammographic targets. Using FDA-trained inspectors to score phantoms, the mass and speck scores were significantly higher with both higher luminance and greater contrast (Pisano *et al.*, 2001).

A study was conducted with LCD displays and pulmonary nodules, in which the medical display had a higher calibrated luminance. Overall, there was a statistically significant difference ($F = 4.1496$, $p = 0.0471$) between the medical-grade color display and the COTS color display in terms of receiver operating characteristic area under the curve values, with the medical-grade display yielding higher diagnostic accuracy (Krupinski, 2009).

The probability of object detection increased when the visual adaptation luminance value matched the ambient illumination in the room (Chawla & Samei, 2007).

Why not just use Window and Level to increase the dense tissue contrast? Indeed, adjusting W/L is an important method in many cases, as it increases the apparent contrast of some portion of the medical image. But it favors one range of image density at the expense of other ranges. So, while it can make some things more conspicuous, other things become invisible. This is perhaps what happened with the fatty breast tissues in the ACRIN trial. With the Fischer system, in particular, the acquisition processing favoring dense breast tissue possibly worked to the detriment of the contrast in the fatty breast tissue (Pisano *et al.*, 2009).

A study sponsored by the National Cancer Institute conducted at the University of Pittsburgh studied the effect of luminance on chest X-ray diagnosis. The detection of pneumothorax, interstitial disease, and rib fracture showed statistically significant differences ($P < .05$) due to luminance (Herron *et al.*, 2000).

DuraLight Nova's higher luminance and contrast are designed precisely to provide these clinical advantages.

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6. Conclusion

The DuraLight Nova backlight brightens the softcopy image, maintaining a calibrated luminance of 1000 cd/m^2 for the lifetime of a display. Moreover, its I-Luminate function further boosts the luminance while preserving the DICOM calibration.

The clinical benefits of greater luminance are superior detection, less image manipulation, and faster decisions. The minimum size of detectable objects is reduced without increased X-ray dosage. The conspicuity of small objects in both dense and fatty tissue is increased.

The higher luminance boosts the apparent contrast of clinical images and allows the use of more ambient light. With more ambient light, radiologist fatigue is reduced and the work environment is more pleasant. The ability to illuminate a film for refererence is a convenience while making the transition from film to digital mammography.

Without decreasing any other parameter, DuraLight Nova increases:

- Contrast
- Apparent contrast
- Spatial resolution
- Display lifetime

With a powerful, uniform luminance, DuraLight Nova enhances conspicuity of medical details, so radiologists can make accurate interpretations faster and more comfortably.

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