

White Paper

Diagnostic Color Displays

What's inside?

- Why is color becoming more important for diagnostic imaging?
- How does a color display work?
- What are the requirements of a diagnostic color display?
- What are the clinical benefits of a more versatile diagnostic display?

Geert Carrein
Product Manager
Medical Displays & Systems
Barco
geert.carrein@barco.com

Barco
Pres. Kennedypark 35
B-8500 Kortrijk, Belgium

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ABSTRACT

Over the past decade digital medical imaging has replaced conventional film imaging in a large number of hospitals. Technological innovation in image acquisition technology, sophisticated image handling and advanced display technology has brought substantial advantages for patients, radiologists and referring physicians. During the initial transition from film reading to softcopy reading, radiologists all over the world used state-of-the-art, high-resolution monochrome CRT displays. This high-end display technology was rather short-lived as a major new display breakthrough technology appeared in the desktop display market, offering a number of key end-user benefits, such as increased brightness, small footprint and low power consumption. Medical display vendors soon started to adapt this promising technology to the specific needs of the medical imaging market (high resolution, monochrome displays, etc.) and many new medical display products based on this innovation were introduced on the medical imaging market over the last 3 years.

Now again, we are on the verge of a new display generation entering the medical imaging market. Below, several reasons are given why there is a need for a new display technology.

1. At this point in time most diagnostic imaging is still done on conventional monochrome LCD displays. New trends in image acquisition technology however impose the use of more advanced image presentation techniques.
2. We have witnessed that the successive generations of acquisition devices have brought new scanners to the market that deliver images of substantial higher spatial resolution and with an increased number of slices. This has led to an explosive growth of image data sets.
3. For radiologists, it becomes virtually impossible to view thousands of images, so software vendors started to rethink their image presentation concepts. This has resulted in advanced viewing software with novel 3D image handling concepts, enabling radiologists to look at the images in a more natural 3D way. The use of color to segment different parts of the body became standard in these new viewing concepts.
4. As radiology is continuously seeking to improve diagnostic reading, new medical imaging techniques such as image fusion were introduced, which require the use of advanced color displays to properly view the images.
5. Examining pathology images becomes more and more part of daily practice. Most reading stations however are not suited to do this properly, although accurate representation of color data can be vital.
6. As hospitals are constantly improving their cost-base, patient data is merged into one EMR (Electronic Medical Record). Without any doubt a versatile diagnostic color display is best fit to display all the information stored in the EMR.

This paper outlines how color displays work and addresses their minimum requirements and concludes with the clinical benefits that this new generation of displays is able to offer.

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Barco
Pres. Kennedypark 35
B-8500 Kortrijk, Belgium



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1. WHY DO WE NEED A MORE VERSATILE DIAGNOSTIC COLOR DISPLAY SYSTEM?

Medical grayscale display systems have gained strong market acceptance, mainly because they fulfill a number of user requirements that are not available on standard color flat panel displays. The main features that explain the preference for monochrome medical displays over color displays are:

- *High-resolution requirements for multiple X-ray applications*
- *Superior image contrast compared to color displays*
- *Superior brightness*
- *Perfect grayscale response*
- *No real need for color*
- *Excellent 2D imaging performance*

Market requirements however can change rapidly due to the introduction of new imaging technologies. Image fusion technology for instance requires high-end diagnostic workstations to include a color display, in order to visualize the color data acquired by some modalities. Some new modalities also deliver additional color information, which needs to be visualized somehow.

The explosive growth of the acquired image data in some modalities requires novel ways of presenting the image data to the radiologist. The use of color opens new ways in this respect.

Rapid growth in the 3D imaging segment creates new challenges in terms of workstation performance. Conventional 2D based viewing stations can no longer accommodate this, nor do they have the performance level to further increase patient throughput or improve hospital efficiency.

In addition, radiologists also face space problems because of the installation of multiple workstations on their desk; some of them optimized for color based administrative procedures, some of them optimized for viewing grayscale medical images.

Needless to say that in order to save space and cost, there is a strong market demand to merge all applications on a single more versatile workstation, the so-called integrated desktop.

In particular, as hospitals continue to increase their global efficiency, enormous efforts are being made to merge all patient data into a single Electronic Medical Record (EMR).

As a result, displays will increasingly be used to look at a variety of medical data.

Future displays should take this into account as optimal display settings can depend on the application at hand. Reading medical images for example requires different display settings than those required for text reading. Failing to do so might result in ergonomic discomfort.

Although existing standard color LCD displays continue to improve, their insufficient resolution, luminance and contrast prohibits using them for a broad range of medical viewing applications. Needless to say this opens opportunities for medical display vendors to design products that do meet those new requirements.

2. INTRODUCTION TO LCD TECHNOLOGY

Liquid Crystal Display (LCD) technology is based on the optical properties of some materials that can alter their transparency under the influence of an electrical signal. By applying the proper signal, the material becomes either completely transparent or completely opaque. If this material is placed between an observer and a white light source, one can change the intensity of the light source from full white to black by applying the proper electrical signal. If in addition a transparent color filter is added in front of the material, the observer will see a light source changing from bright red, green and blue to black depending on the color of the filter used.

In practice, an image is split up in small picture elements (pixels) and a small individual cell is assigned to each pixel. By controlling the transparency of each individual cell, each pixel can take values from fully bright to dark.

In today's state-of-the-art display technology, the light source is composed of tiny fluorescent lamps (CCFL: Cold Cathode Fluorescent Lamp). This is called the backlight. In practice a very powerful light source is required as the efficiency of the optical stack is very low. Only a very small part of the light generated by the light source will leave the front of the display.

By further splitting up each individual cell in 3 sub parts and adding a color filter on top of each of these so called sub-pixels, one can create a color display. When these filters are not placed on top of each cell, the result is a monochrome medical display.

As can be noticed from the image below (Figure 1), the composition of the optical stack is quite complex. All the components of this stack are subject to short and long-term changes (temperature, stability of circuitry, aging, etc.), which can substantially change the optical properties of these materials. To guarantee that the resulting medical image is stable in time, it is therefore mandatory that the optical stack be controlled by some means. (For details see 4.2)

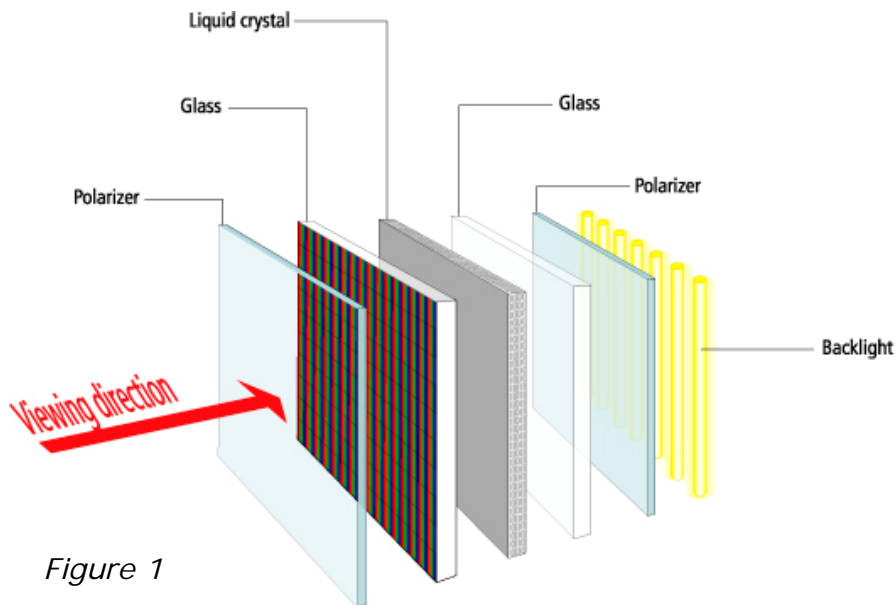


Figure 1

3. WHY DO EXISTING MEDICAL COLOR DISPLAYS OFFER LESS LUMINANCE THAN THEIR MONOCHROME COUNTERPARTS

It is obvious that the brightness of the display will be determined by the intensity of the backlight. By applying more powerful lamps in the backlight a brighter display can be obtained. However, there is a limit to increasing the light output, as more powerful lights will result in substantial higher heat dissipation inside the backlight. In addition, a high luminance can only be guaranteed for a certain amount of time, as the backlights will become less efficient over time. State-of-the-art monochrome displays are driven by very efficient lamps and can give the largest light output possible without jeopardizing display reliability.

By applying a colored filter on top of each cell we obtain a much more versatile color display. Such a display however will have a substantially reduced light output (or lower luminance). This is easy to understand if we look at the nature of visible light. White light is composed as a mixture of all spectral colors ranging from violet to red. By sending white light through a prism we can easily split it up into the individual spectral colors. A similar phenomenon occurs quite often in nature and is called a rainbow (see Figure 2). If, for instance, the light falls on a blue colored filter, only the blue part of the light will pass through the filter. Because the filter is completely opaque for green and red light, about 2/3 of the light passing through the blue filter gets absorbed. A similar reasoning can be made for the green and red filter. In practice, for a given backlight, a color display will only achieve about 1/3 of the luminance of its monochrome equivalent, as this display has no colored filters that absorb part of the light (see Figure 3).

A major innovation of Barco's new CORONIS® COLOR DIAGNOSTIC LUMINANCE displays is their innovative backlight design. By combining proven, long-lasting DURALIGHT® backlight technology with a new thermal management concept, the new backlights reach luminance levels previously thought to be impossible. As a result, diagnostic luminance levels can now be achieved for the first time on a color display.

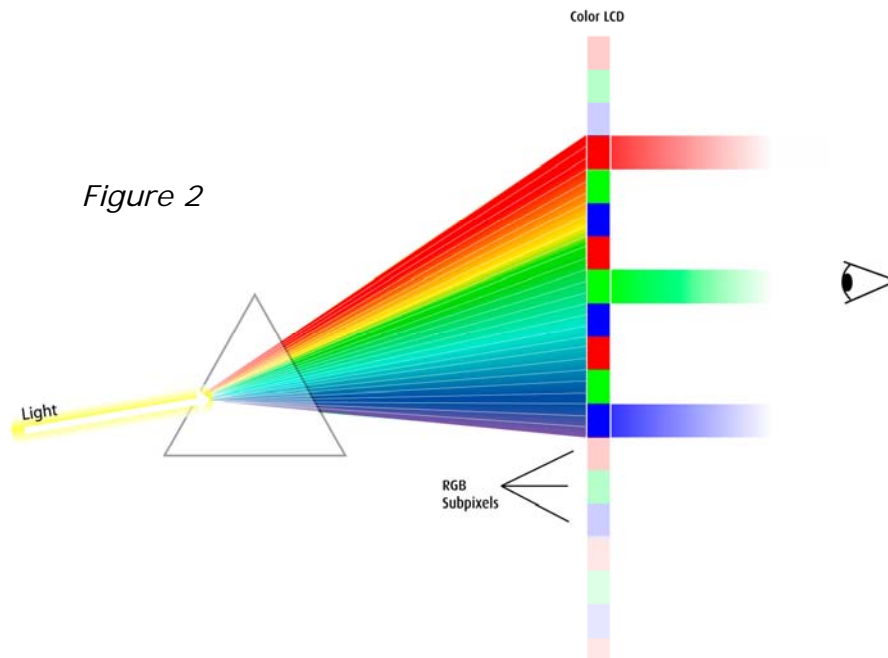
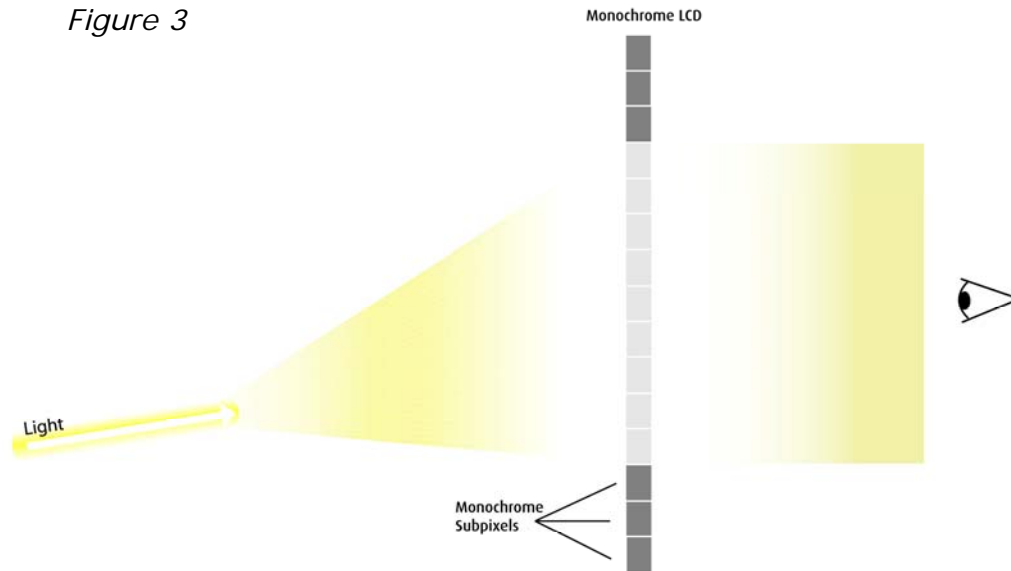


Figure 3



4. WHAT ARE THE REQUIREMENTS FOR A DIAGNOSTIC COLOR DISPLAY SYSTEM?

If we want to use color display systems for diagnostic reading we should achieve a quality and performance level that is similar to that of a monochrome display.

The following parameters have a major impact on the final image quality and performance of a monochrome display:

1. Image resolution
2. Image stability
3. Sustainable maximum luminance
4. Contrast ratio
5. Grayscale display function (DICOM p14 GSDF)
6. Luminance uniformity
7. Viewing angle
8. High image throughput
9. Use of sophisticated medical viewing applications

4.1 IMAGE RESOLUTION

Digital imaging offers the advantage that radiologists can zoom in on any region of interest. Although in principle any medical image could be viewed on a display station with a very low resolution by zooming in on the region of interest, in practice this leads to a lot of image manipulation and substantially reduced image throughput. In addition, if the display has a resolution that is too low, disturbing artifacts will start to show up.

Also from an image quality point of view there are some minimum requirements for the resolution of the displayed image.

ACR/NEMA has defined a minimum spatial resolution of 2.5 lp/mm for X-ray film reading. This should allow the radiologist to see sufficient detail at the first glance. Such a resolution corresponds well with the resolution offered by a 3MP monochrome display, which is now widely used for X-ray viewing.

To obtain similar image quality on a color display we need at least a spatial resolution of 3MP on a color display (1536 x 2048 pixels).

4.2 IMAGE STABILITY

Radiologists expect that the image quality of their images remains stable over time. Although the data stored in the computer archive is purely digital and therefore stable over time, the perceived image on a display workstation is not. Aging and environmental changes can substantially affect the perceived image. Therefore, displays intended for medical use should have a means to stabilize the image quality over time. Recognizing this need, Barco developed its I-GUARD[®] technology, a photometer technology integrated in its displays that is capable of stabilizing and even calibrating the image quality of monochrome displays.

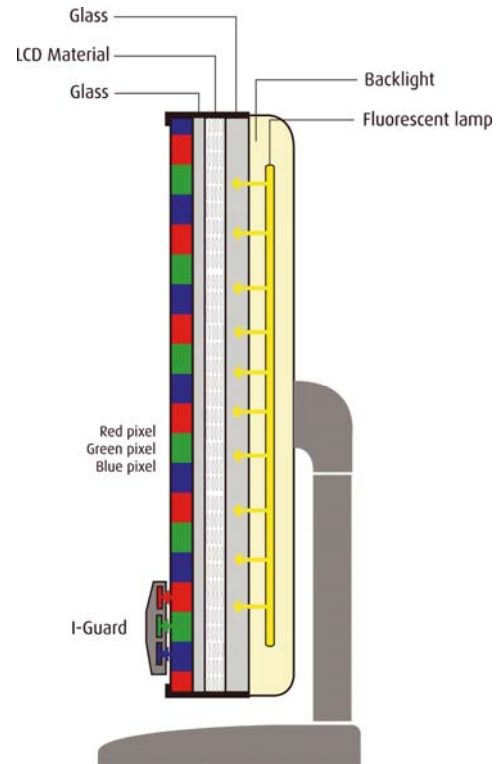
With the advent of the new diagnostic color display and based upon its broad experience with the existing I-GUARD[®] technology, Barco developed its second generation I-GUARD[®] technology. This next generation I-GUARD[®] technology brings:

- much faster calibration speed (8x)
- improved low light measurement performance
- better viewing angle independence
- improved photo-sensor technology

The I-GUARD[®] continuously measures the light output of the Red, Green and Blue contributions at the front of the display and counteracts any changes that might occur over the short and long term.

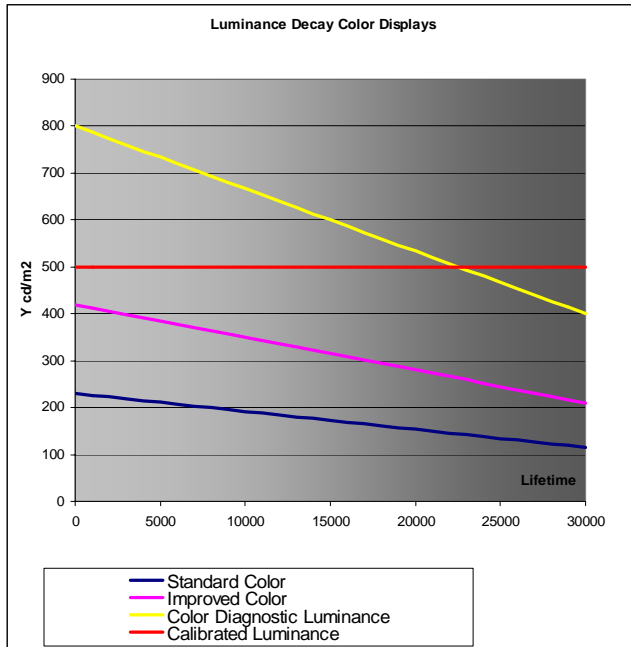
By looking at the image the same way as the radiologist does, the I-GUARD[®] guarantees that the image quality remains constant over time.

In addition to the stabilizing function, the I-GUARD[®] also precisely measures and calibrates any DICOM JND as defined by DICOM Part 14 with a 10-bit precision. Needless to say that this technology sets a new image quality standard for medical color displays.



4.3 SUSTAINABLE MAXIMUM LUMINANCE

As outlined before, LCD color displays have a substantially lower light output than monochrome versions. In addition, the backlights of all displays (monochrome and color) will decay over time.



The lifetime of a backlight is usually specified as that point where the luminance has dropped to half the initial typical luminance.

In many cases, this luminance level is not sufficient for diagnostic purposes. AAMP, DIN and other organizations recommend luminance levels that are determined by the application and environment in which displays will be used. For X-ray diagnostic viewing the luminance in a diagnostic reading room is typically set at 500 cd/m². (145.9 fL) With this calibrated luminance, the backlight of the monochrome display will typically last for 20,000 hours.

One could of course argue to set the luminance to a lower level to gain lifetime, but this will immediately reduce the number of available JNDs. It has been shown that subtle lesions in the image can be overlooked if the available JND-range becomes too small (up to 25% more missed detections).

A second important argument against lowering the brightness is the negative impact this has on the image throughput. Some studies conclude that radiologists need substantially more time to find subtle lesions if the brightness is lowered.

An important specification of a monochrome display is the luminance at which it is calibrated. The calibrated luminance is the luminance level that can be maintained over the lifetime of the display. Color displays on the other hand are specified by their initial typical luminance. The calibrated luminance is usually only 50-60% of that initial value.

Barco's CORONIS[®] COLOR DIAGNOSTIC LUMINANCE displays specify their calibrated luminance the same way as monochrome diagnostic displays.

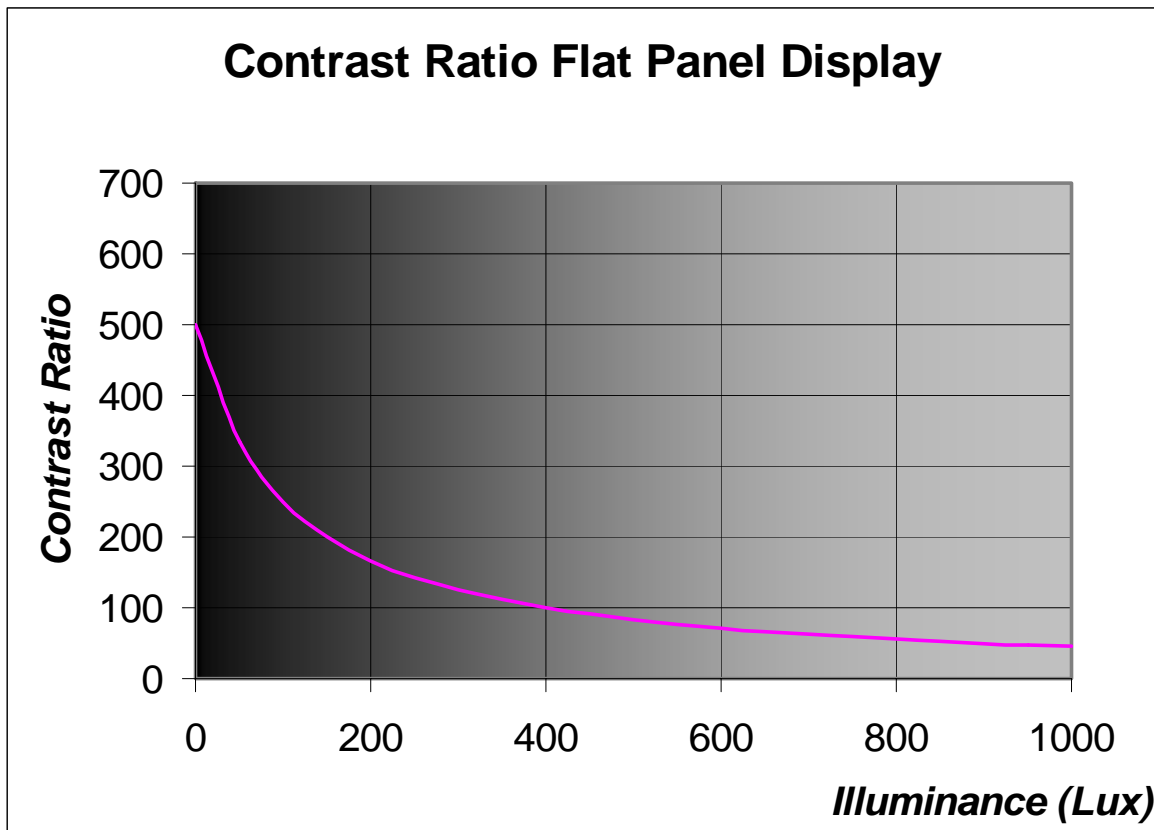
4.4 CONTRAST RATIO

Next to the calibrated luminance, the contrast ratio is a very important characteristic of a medical display. The higher this ratio, the more DICOM JNDs the display will be able to render. But how do we define contrast ratio?

The contrast ratio of a display is defined as the ratio of the white luminance level over the black luminance level. If you have a display with a white level of 500 cd/m² and a black level of 1 cd/m² then the contrast ratio is 500:1 = 500. This is valid for a display that is used in a completely dark reading room.

Recent guidelines published by the AAPM and DIN illustrate that the illumination level of the reading room can substantially reduce the contrast level by adding an unwanted amount of diffuse reflection to the display luminance. Imagine that the equivalent of 1 cd/m² is added to the screen luminance for black and white. In such a reading room the contrast ratio would drop to $(500+1)/(1+1) = 255.5$. This is just above the recommended AAPM value for diagnostic reading.

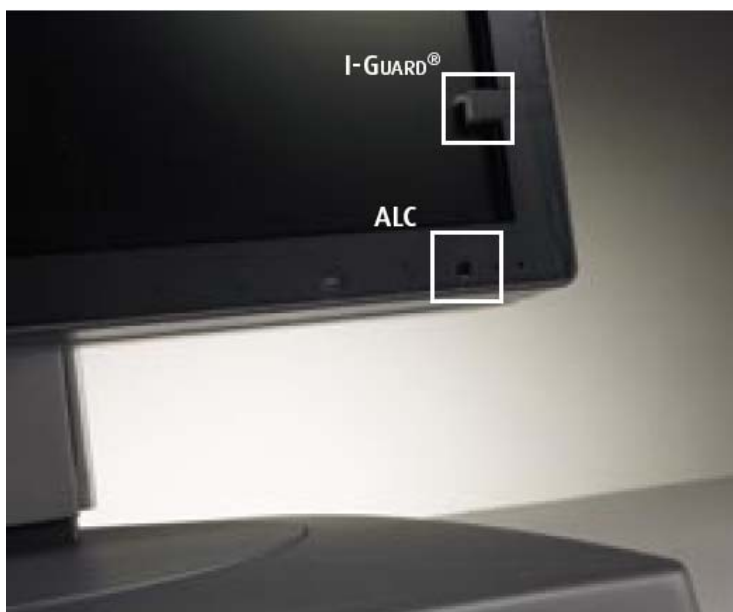
As can be seen from the graph below, the typical final contrast ratio will change substantially as a function of the ambient illumination.



Given this reduced contrast ratio, a substantially lower number of DICOM JNDs can be rendered on the display. DICOM, AAPM and DIN recommend that the JNDs should be re-rendered if the contrast ratio changes too much due to changes in the illumination.

According to the AAPM TG 18 guidelines, every medical display should have a good contrast ratio, preferably higher than 250, taking into account the ambient illumination level. In addition, the displays should have a means to recalibrate the DICOM JNDs as a function of the illumination level.

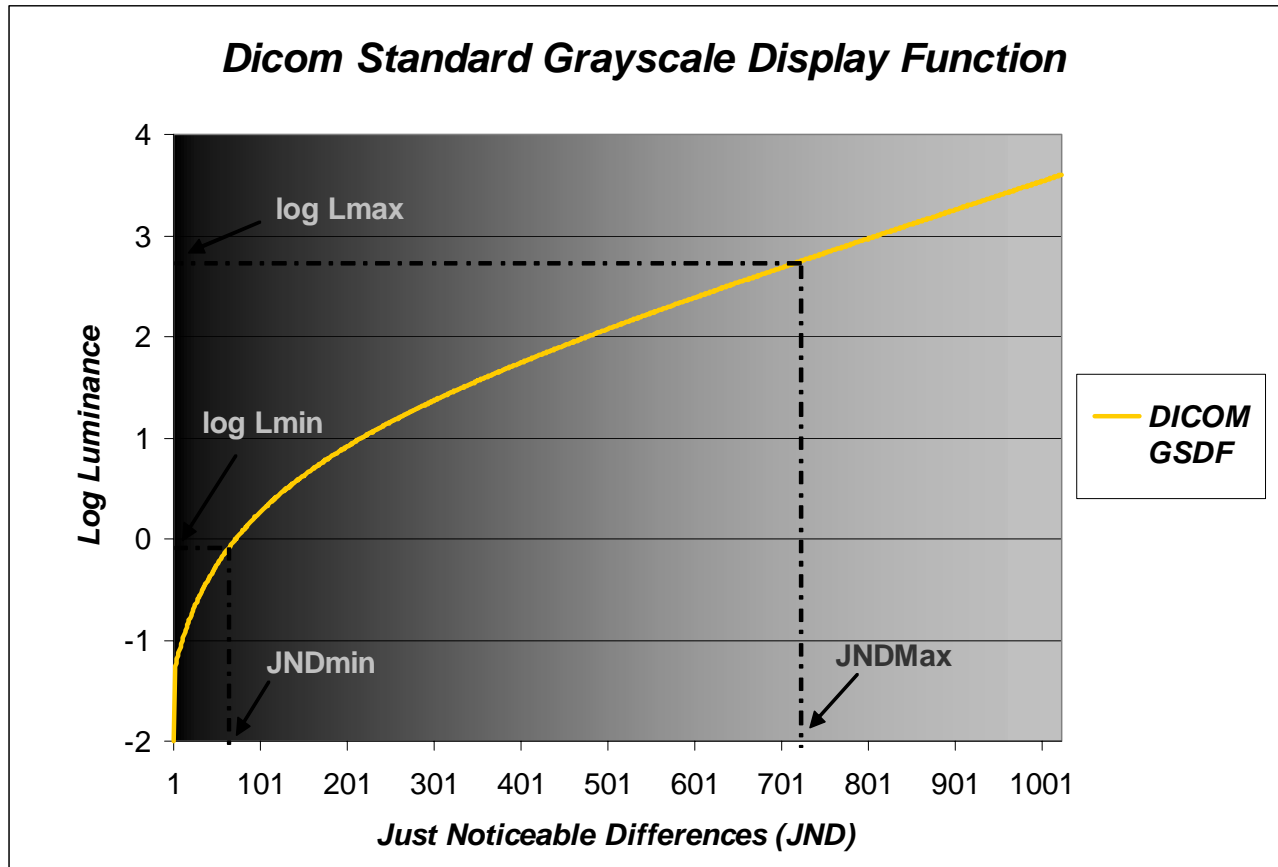
For its next generation CORONIS® displays, Barco developed the innovative ALC (Ambient Light Compensation) technology. ALC makes sure that the display's brightness is being adjusted under different illumination conditions, to ensure proper DICOM GSDF without any human intervention. Previous display families had a pre-stored DICOM table in the display that was optimized for a dark reading room (illumination level was assumed to be 0 Lux).



4.5 GRAYSCALE RESPONSE FUNCTION

To ensure the consistent display of digital medical images across all types of emissive display systems, one needs to have a consistent way of translating the digital pixel values into their corresponding absolute luminance values. This is achieved by using the Standard Grayscale Display Function, a contrast sensitivity function based on the Barten model. It defines the minimal contrast steps that can be distinguished by an average observer over a predetermined luminance range from [0.0 up to +/- 4000 cd/m²]. Within this range, one can fit 1024 of these Just Noticeable contrast Differences also known as JNDs.

A graphical representation of this GSDF function can be found below. Commercially available displays will not be able to render all dicom JNDs as they lack sufficient luminance. In practice displays are limited to render JNDs in a sub-range determined by the minimum and maximum luminance of the display. (Lmin, Lmax, JNDMin, JNDMax)



In addition, the native behavior of a display does not match this GSDF function and differences among brands, models and even units of the same model show large differences in how they translate the digital pixel values into luminance values.

To comply with the DICOM GSDF function, medical displays must have a means to calibrate the light output. In order to calibrate and later on check the luminance of each such JND one needs an optical feedback system that can measure the individual luminance levels of every JND. For monochrome displays this can be achieved by using a monochrome photometer. As color displays are using 3 basic colors (red, green and blue) the optical feedback system is more complex and one needs a more advanced color measurement device to perform the DICOM calibration. Such a system is now standard available on Barco's new I-GUARD®.

Below you see 2 possibilities on how the DICOM calibration is done on a medical workstation display. The first one is done with an external sensor. The second one is with the advanced integrated Barco I-GUARD®.



External sensor



Integrated I-GUARD

The advantage of the integrated measurement device is twofold:

- It can compensate for short- and long-term luminance and chrominance drifts inherent to the normal display operation.
- It can perform intervention-free DICOM calibration and QA checks.

In daily practice most medical diagnostic displays are DICOM calibrated for a white luminance of 500 cd/m². As can be observed from the graph above, the display will be able to render about 700 JNDs for this white luminance level.

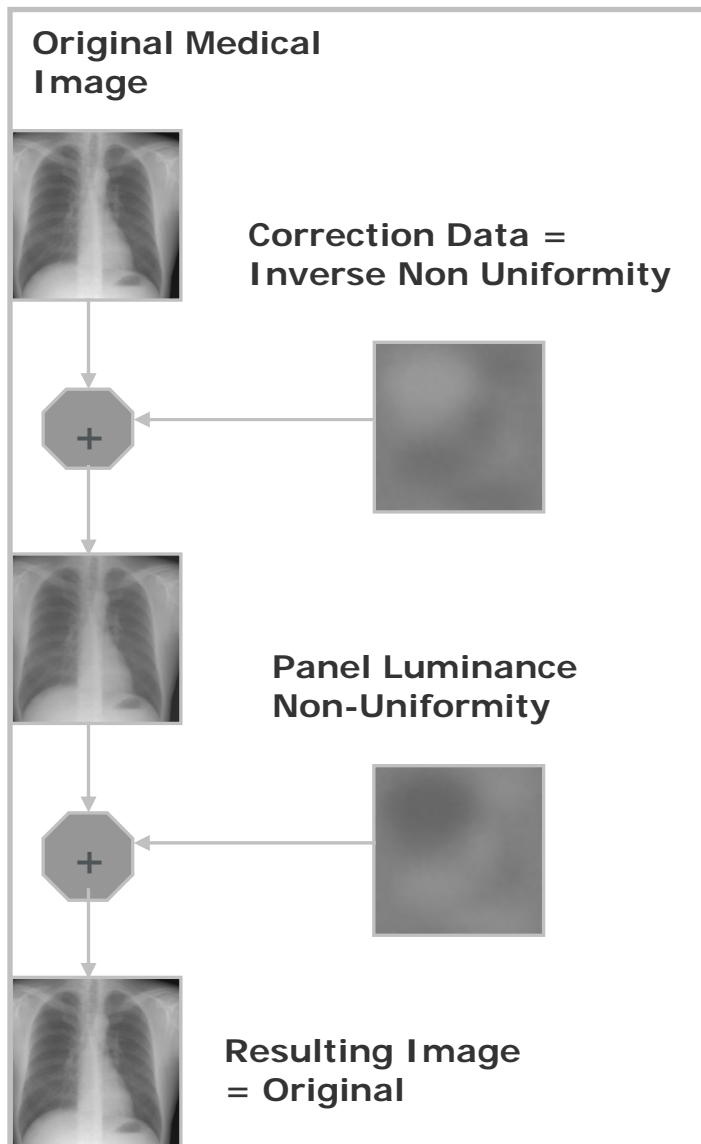
The new generation CORONIS® displays are able to render the individual DICOM JNDs with a 12-bit precision (= 4096 shades of gray). With this resolution each JND can be rendered with an astonishing precision of $700/4096 = 0.17$ JND/Driving Level, far below the visual threshold of any observer and clearly redefining the standard for diagnostic precision.

The more versatile diagnostic color display offers some additional challenges in order to calibrate it properly to the DICOM p14 standard:

- There are 3 channels to calibrate (red, green and blue) as opposed to only one on a monochrome display. Hence, the calibration speed and performance becomes an issue.
- Equal changes in R, G, B values result in unequal luminance changes. Because of this, it is more difficult to select the closest DICOM luminance that can be rendered on the diagnostic color display.
- Color photo-sensor technology is far more complex

The new I-GUARD® brings a solution for all these challenges. Integrated as a tiny front sensor on every display, the new I-GUARD® offers intervention-free calibration and QA.

4.6 SPATIAL LUMINANCE NON UNIFORMITY



LCD technology is known for its non-uniform behavior across the screen area. This spatial non-uniformity adds an unwanted pattern to the original medical image and can obscure subtle lesions.

In fact it can be shown that for each pixel of the display a slightly different DICOM GSDF function applies than the DICOM function, which was calibrated during the DICOM calibration process.

On average errors up to 25 JND's are not uncommon. A detailed description is given in reference [10].

Uniform Luminance technology

Barco's new generation of CORONIS® COLOR DIAGNOSTIC LUMINANCE displays features Uniform Luminance Technology. With this technology the LCD spatial non-uniformities for each gray shade of the display are characterized and stored in the display. When a medical image is presented, the unwanted non-uniformity pattern is added to the image. However, by correcting it with the inverse non-uniformity pattern this unwanted distortion cancels out.

As a result the radiologist sees the image as it was originally presented.

With their unique Uniform Luminance Technology, the new generation CORONIS® displays achieve the best image uniformity available on the market today.

4.7 VIEWING ANGLE

The transition from CRT to LCD based display technology has not led to an improvement of all display parameters (12). Some image quality was sacrificed in exchange for other benefits of the LCD display technology. In particular the viewing angle is lower than the one we were familiar with on the light box or former CRT display. Especially as modern workstations use a substantial amount of display real estate; it is important that displays have an excellent viewing angle as they will often be looked at from multiple angles. What's more, when used for teaching or when a second opinion is required, having an excellent viewing angle is mandatory.

Today, a number of different LCD technologies exist, all of which have different viewing angle characteristics. More specifically the IPS (In Plane Switching) and VA (Vertical Alignment) yield good viewing angle characteristics.

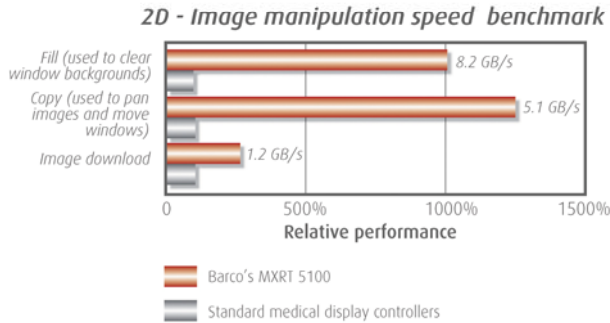
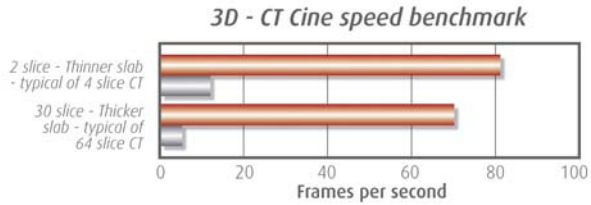
While evaluating different technologies for medical imaging, radiologists have shown a strong preference for IPS technology. Unfortunately the on-axis contrast and light efficiency of IPS technology is somewhat lower than the VA based technologies.

Barco has built its new diagnostic color display based on this IPS technology and has optimized the display for excellent viewing angle characteristics to accommodate common viewing practice.

4.8 IMAGE THROUGHPUT

Color displays require much more data than monochrome displays. As each pixel on a color display is characterized by 3 independent RGB values, color displays will use 3 times more data than an equivalent monochrome display. The result is a 3 times slower performance on a color display.

Because of this, multiple headed display systems can react slowly to image updates in particular when large cine-loops are played back. Also they can have a slow and awkward reaction to mouse movements. The higher the native resolution of the display, the more problematic this becomes. Therefore, medical grade diagnostic color displays should be driven by high-performance display controllers capable of handling the enormous data amount that is required for today's multi-head high resolution displays.



In anticipation of this requirement, Barco introduces a new generation of medical display controllers with substantially improved performance specifications that will satisfy even the most demanding medical viewing applications.

The adjoining graph indicates the performance improvement available on new CORONIS® displays.

4.9 USE OF SOPHISTICATED MEDICAL VIEWING APPLICATIONS

Viewing applications increasingly make use of sophisticated user interfaces that apply color to better highlight pathologies and the important parts of the body.

Example:

Head and Neck

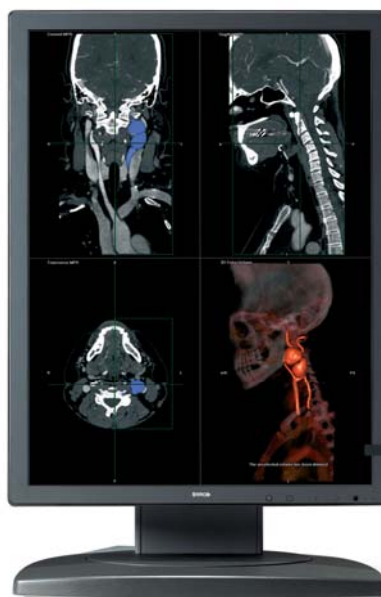
The MPR views and 3D color volume rendered image are from an MDCT scan of a patient with a massive left carotid artery aneurysm, demonstrating the relationship of the aneurysm to the carotid arteries.

Pathology:

Massive left carotid artery aneurysm.

Resolution:

The MPR views show the true extent of the aneurysm. The 3D color volume rendered image demonstrates the carotid arteries surrounding the aneurysm, providing the information required to demonstrate the relationship of the carotid arteries to the mass. 3D color volume rendered images are created for the surgeon to assist with preoperative planning.



5. CONCLUSION

Medical diagnostic imaging is evolving very fast, resulting in ever increasing image data sets with richer information content. Novel viewing software to visualize these data sets requires the use of more versatile viewing stations capable of handling diagnostic data, patient data, pathology images or simply the EMR.

The new generation of diagnostic color displays will meet this versatility requirement and at the same time offer the radiologist image quality that is similar to what was available on monochrome displays in terms of brightness, contrast, viewing angle, uniformity and DICOM P14 compliance under all viewing angles.

As hospitals continuously look to improve their efficiency, image throughput of the viewing system is of vital importance. Barco's new diagnostic color displays will help you to achieve this by:

- allowing faster diagnosis through high display performance
- enabling the use of advanced viewing software
- faster and improved workflow through the use of the latest display controller technology
- improved usability of CAD software

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