White Paper

Optimizing Image Quality in the Radiologist's Field of Vision

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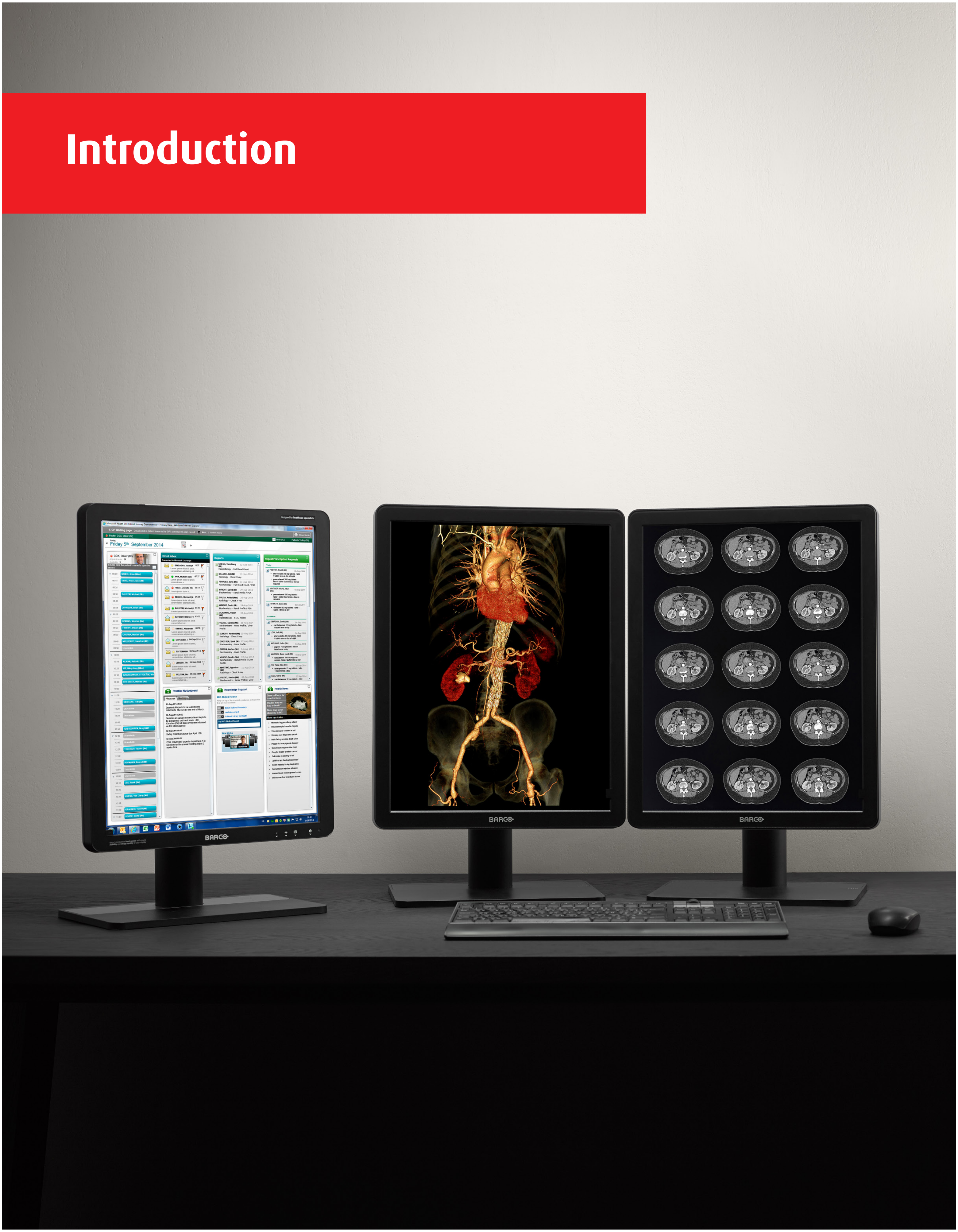
Visibly yours

What's inside?

- Extent of our field of vision
- Maximum image quality over the field of vision

Introduction



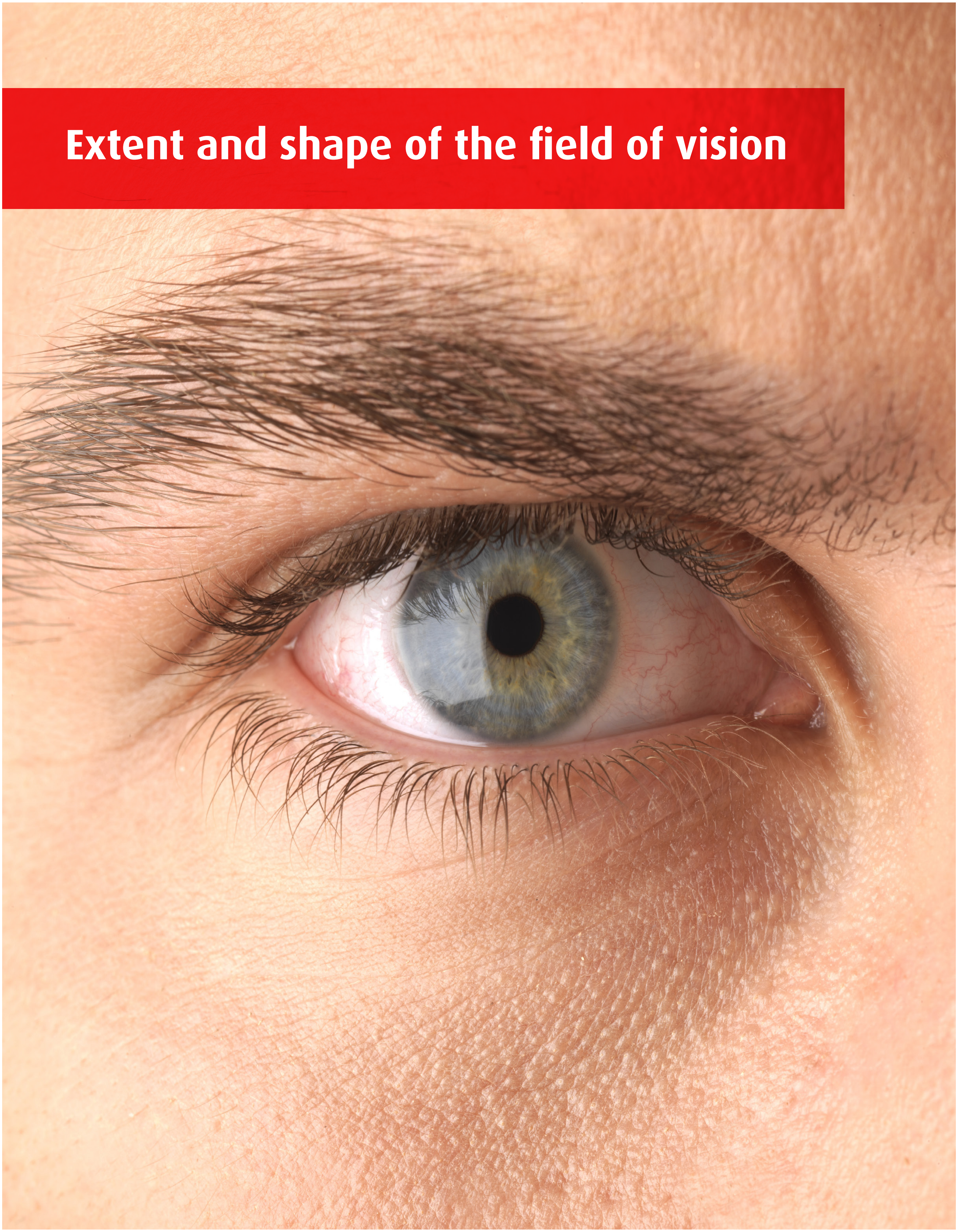
1. Introduction

As recent evolutions in medical imaging have produced more complex exams, it has become necessary to develop more advanced, multi-functional display technologies. Until recently, display technology advancement has not kept pace with the demands of modern imaging. Complex multi-headed workstations still occupy a large physical footprint in today's typical radiology rooms, where workstations can have a mis-matched array of displays with varying resolutions, color appearance, or indeed no color monitors at all.

One of the real disadvantages of these large display configurations is the resulting ergonomic strain experienced by a radiologist due to the need to frequently move his head to view all of the images in a single study. In addition, each time he refocuses on a particular region of interest or significantly increases his dwell time on a large display, he loses productivity. The fundamental reason for this is that the human eye reaches its optimal viewing performance in a relatively small field of vision, resulting in more efficient (and thus more productive) reading. Therefore, if display performance could be optimized for the field of vision, one could theoretically maximize productivity while minimizing occupational stress.

This paper describes these challenges and presents a solution that optimizes display performance in accordance with the visual characteristics of the human eye. The challenge begins with first considering the natural capabilities of the eye, and then determining what field of vision and image quality characteristics make reading most accurate and comfortable for the radiologist. The balance between filling the useful part of a radiologist's vision with information and enabling a more ergonomic viewing experience is achievable with the latest display technologies. After years of trials, development, and testing, Barco is ready to offer a product that truly optimizes the field of vision to significantly improve the image reading experience.

Extent and shape of the field of vision



2. Extent and shape of the field of vision

When we look at a workstation, we have a certain field of vision, which is predominantly a preference for the forward direction. All animals maintain different adaptations to favor certain visual functions. In human eyes, there are zones that favor color, shape discrimination, and motion. Specialty cells called cones, especially effective for seeing colors and fine details, are concentrated toward the center of the eye, and are primarily found in the fovea of our eye. This foveal region largely excludes rods, which are more light efficient and whose function is to see motion.

In the periphery of our eye, there are only rods, while in the middle region, there is a mixture of cones and rods. Our perception of color and shape is limited to about 30 degrees in each direction. Beyond that, while we don't identify shapes, we have the ability to detect motion "out of the corner of the eye". Fig. 1 illustrates that our foveal vision is narrow, i.e., we use it to inspect the details of a scene and to read text. Therefore, it makes more sense from an ergonomic perspective to put important things in the most effective part of our field of vision.

For a medical workstation, the useful part of the field of vision is essentially +/-30 degrees. This is the area where shapes and colors can be perceived (Rosén et al., 2014), and where attention can be drawn to enable the viewer to bring a variety of tools to bear on the information in the medical studies.

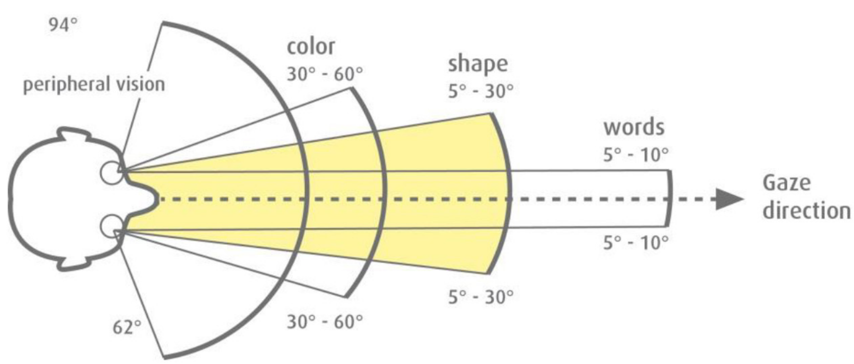


Figure 1: Useful Field of Vision

Based on these circumstances, we can easily see the implications for the radiologist's workspace:

- Display surfaces should be arranged to be in the field of vision
- The field of vision should present as much information as possible
- Diagnostic information should be confined to (or at least concentrated into) a limited viewing angle of +/- 30 degrees

Field of vision – the useful part of our vision

As discussed previously, humans can see things moving using their peripheral vision. They can also see light and dark, or large patches of color without looking directly at them. Our binocular vision represents what can be seen by both eyes; this field is a bit smaller than the total peripheral area covered by the two eyes together (Webb, 1964). However, as seen in Fig. 1 "Fig. 1 – ," it is not our whole peripheral vision or binocular vision that is important, but a subset of both where shapes can be perceived.

As stated, a circle +/- 30 degrees is the useful limit for discerning shapes, because both eyes look at the same point on the screen, sharing a single circular area. Once our eyes detect something in our peripheral vision, we can move our eyes to concentrate our foveal vision on this. However, if we don't notice something in particular, we don't systematically scan the image in an organized way. In fact, radiologists usually only examine a small subset of the image with their foveal vision. With this calculation, it is possible to design the best possible display for our field of vision. Consider the blue rectangle approximating a display in the polar plot below:

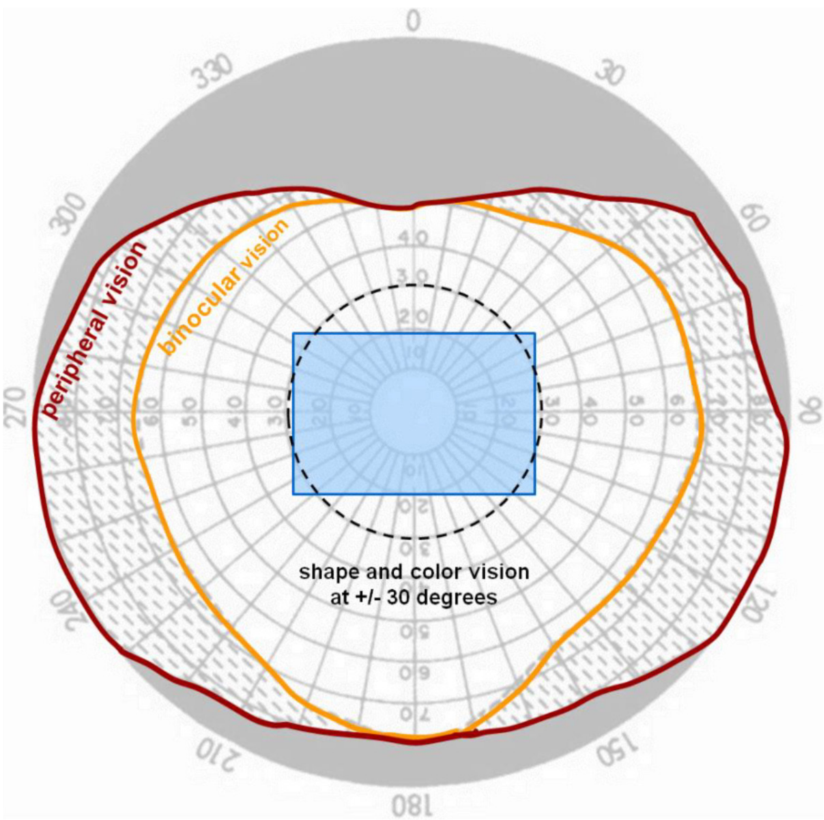


Figure 2: Polar plot of display in Field of Vision

The display (blue rectangle) makes good use of the +/-30 degree range of vision for discerning shapes and colors. Logically, one might expect it to be a circular shape, but for several reasons, it is not. First, our vision has a preference for looking at close objects lower, rather than higher in the normal field of vision. So if we eliminate some of the vertical portion, we focus on a rectangle rather than a square. Second, hardware and software technology expects straight edges. So while an ellipse might be a good theoretical shape, the rectangle above is the optimum practical shape and size that can be used for radiologist work.

However, most display set-ups in typical radiology workstations defy this convention, rather depending upon an array of medical displays to present all of the necessary images in a patient study, as shown in Fig. 3. The left picture below shows four 3 megapixel (MP) displays and the right shows a pair of 5MP displays with an added 2MP color display. In these configurations, displays are often wrapped around the viewer to minimize the difference in focus distance and viewing angle. As a result, more head motion is necessary, even to initially see the information presented.

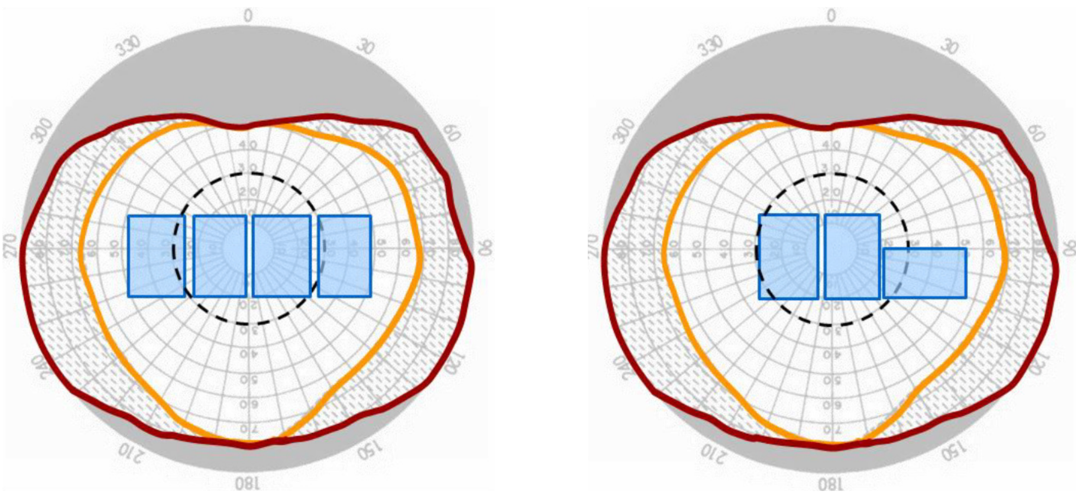


Figure 3: Workstation display extending outside the useful Field of Vision

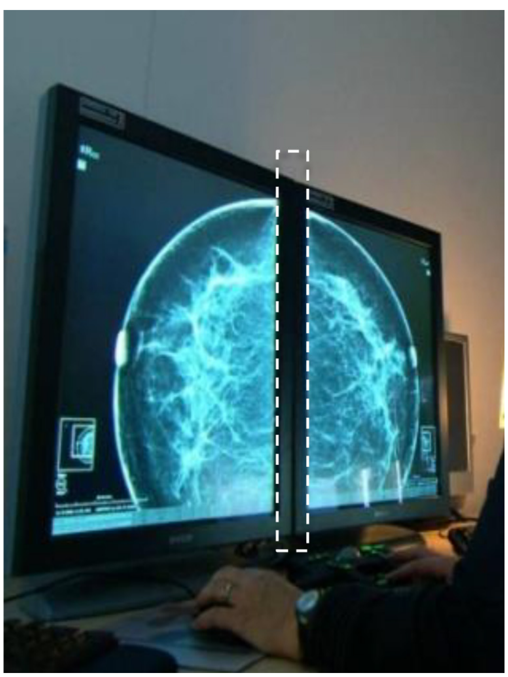


Figure 4: Display bezels occupying center of vision

Given the shape of the field of vision, there is another disadvantage to using multiple separate displays: the bezel (Fig. 4). Few people report the bezel between the displays as a serious problem. Surprisingly, people quickly learn to look past this, just as they look past a bug on the windshield. However, we could clearly use this space more optimally if we filled it with image. In fact, we could add 261cm2 of image, right in the middle of our field of vision!

One step in the right direction is the Fusion format for medical displays that gives radiologists back the center of their field of vision. Barco's fusion format displays were developed to best utilize the center of a person's field of vision exactly where the eye has the sharpest vision. In addition to making the layout of images more flexible, this fusion format has been shown to increase productivity up to 19% (Weschler et al., 2012) when viewing general radiology images on a 6 MP widescreen display versus two 3 MP displays.

The Barco Coronis Uniti optimizes the useful field of vision, offering the maximum real estate, i.e., largest screen area to arrange images and other information at the ideal orientation for the radiologist. Selecting 65cm as the distance from the viewer's eye to the display puts the center at "arms' length" as suggested by the American College of Radiology (Norweck et al., 2013) and puts the outermost corner at 78cm. By placing the center of the display slightly below the eye level and tilting the display downward a little, it fits most comfortably into the field of vision, as shown in Fig. 5. The Coronis Uniti has the same overall pixel count as the previous multi-display configurations and stays closer to the +/- 30 degree range of useful vision.

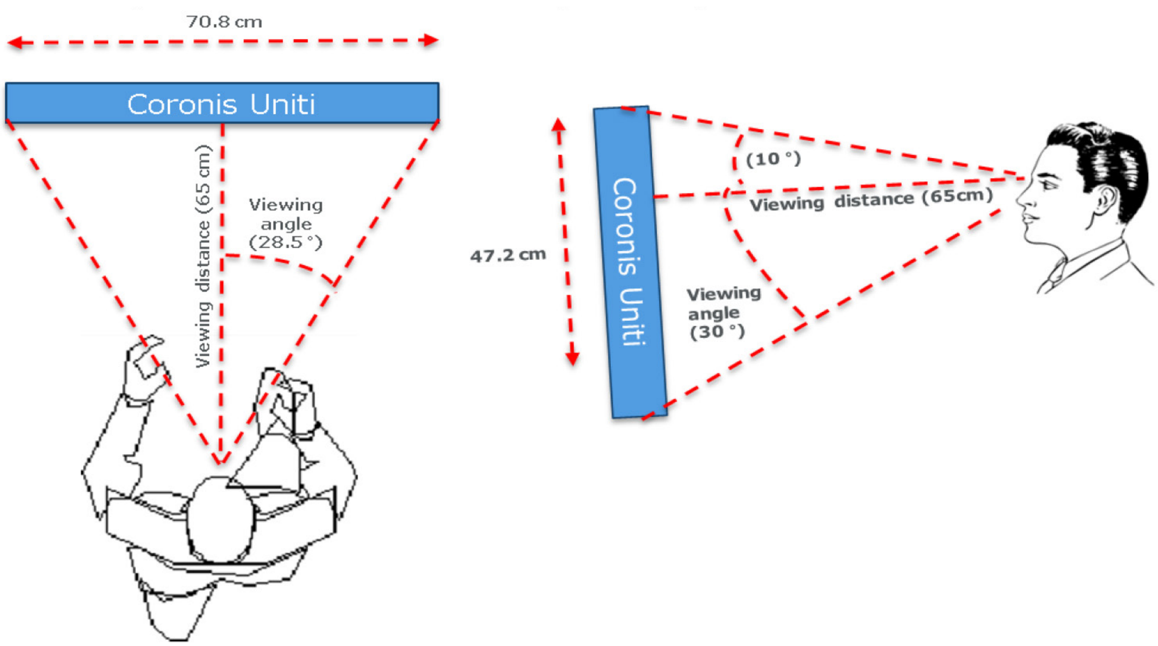


Figure 5: Viewing angle with Coronis Uniti

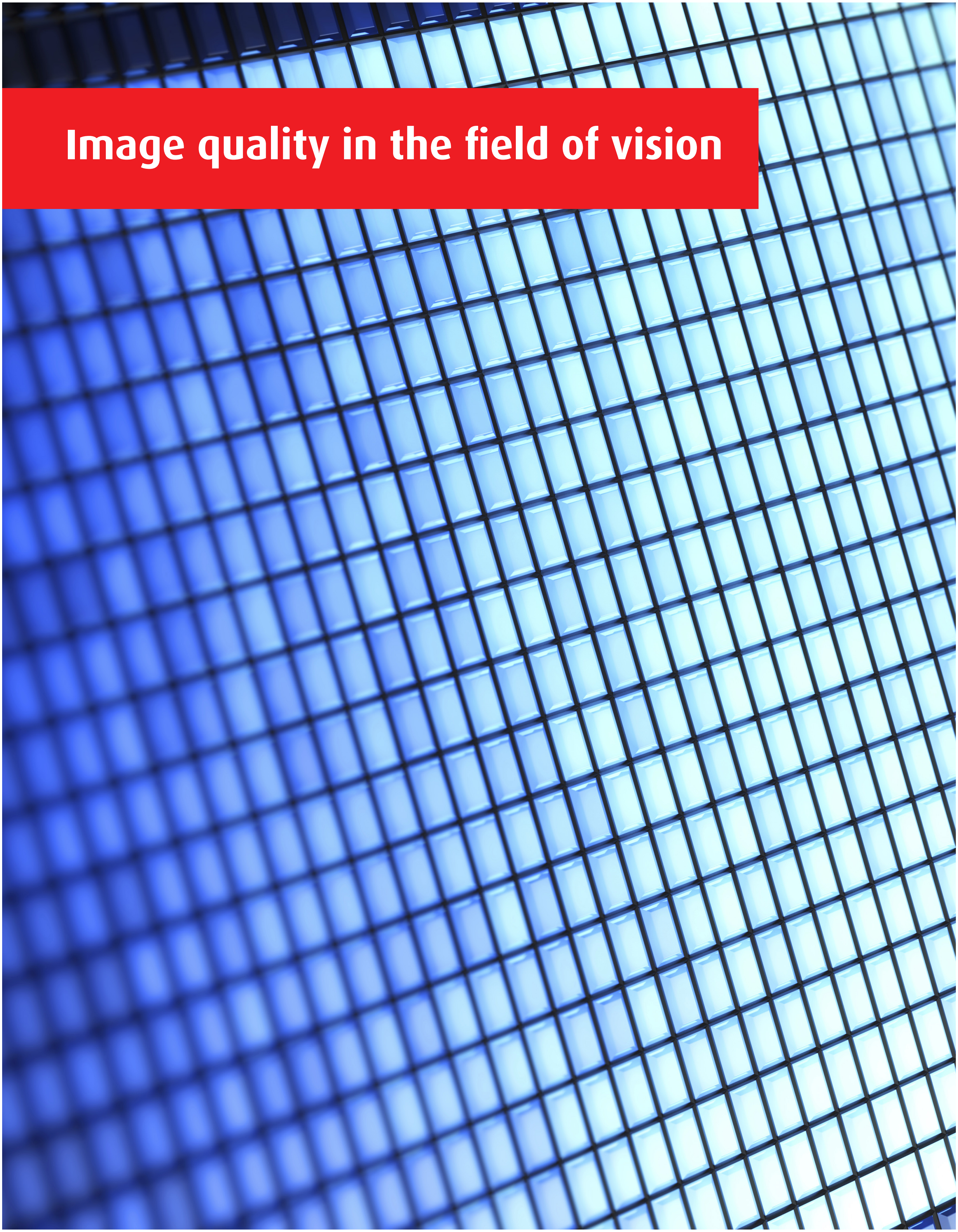
In terms of *what fits in the field of vision*, the difference can be measured in various ways: one simple way is to measure the square inches; a more important measure could be the number of square inches available to display a particular type of medical image (as shown in Fig. 6 below). For portrait images like a chest x-ray, this difference can be up to 25-30%.

Display	Square inches	Square inches in portrait image
Coronis Uniti	514	257
Coronis Fusion 6 MP	415	194
Coronis 5 MP	442	181

Figure 6: Image sizes in Field of Vision

However, to truly understand the difference between Coronis Uniti and other displays, it is necessary to consider the image quality in the field of vision.

Image quality in the field of vision



3. Image quality in the field of vision

The latest and most advanced display technologies maximize the image quality over the field of vision. There are several parameters that influence image quality, which when optimized, can greatly improve what a radiologist can see in their field of vision:

- Local contrast
- Number of pixels
- Amount and distribution of colors
- High and uniform luminance
- Viewing angle

Local contrast

It is important for a display to have good local contrast, so that the field of vision is filled with useful, high contrast detail. This minimizes the need to zoom into the image, enabling the radiologist to read more efficiently while preserving the overall context of the surrounding area.

How do we perceive local contrast? Contrast between tissues and structures enables perception of the shapes, textures and densities in a body. The display contrast, between black and white, is the total range that can be used to arrange all the contrasting structures in the body. Consider a chest x-ray where various structures each use a portion of the overall contrast: the bone of the clavicle uses the brighter values, the lung makes good use of the darker values, and the aortic arch uses the middle of the contrast range. Not only is the contrast of each structure less than the whole range between black and white, the contrast we actually see on the display can be lower than the portion allocated to each range. Essentially, because some light scatters, darker areas of the display are not as dark as they should be.

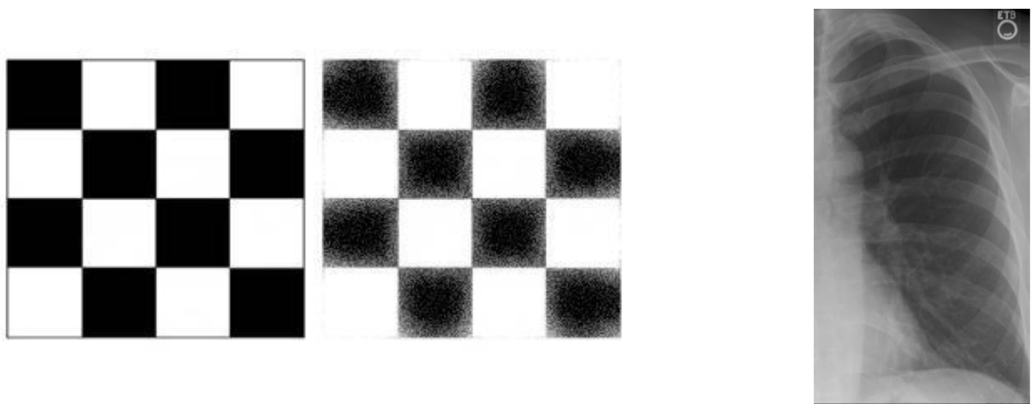


Figure 7: Local contrast

Imagine we represent a detail in the lung field or a mammogram with a simple structure like the checkerboard pictured in Fig. 7 above. The ideal representation is shown on the left, in Fig. 8 (next page). However, the display, much like the human eye, scatters some of the light, making the real representation more like the image on the right. How significant is this effect and how much does it matter? Numerically, this is a big effect.

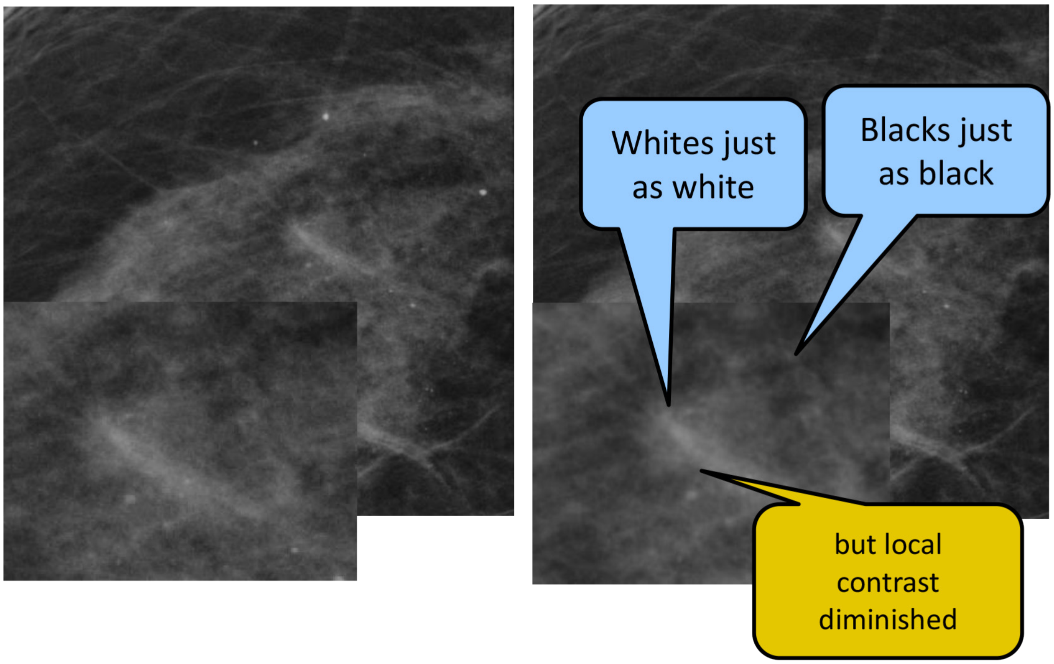


Figure 8: Local contrast affected by scatter

As shown in the table below (Fig. 9), when measuring the contrast between two displays with a solid white then black screen, the Coronis Uniti is measurably improved, with a contrast more than 1100 compared to the 833 presented by the Barco Nio 5MP. But due to the scatter, when looking at fine patterns, a much stronger difference emerges. The Coronis Uniti has good local contrast, while the other display loses much of the image contrast due to scattered light, which brightens the dark parts of the image. In fact, the Coronis Uniti has up to 12X the real local contrast in a medical image, as compared to other medical displays.

	Coronis Uniti	**Nio 5MP**
Coronis Uniti	0.9	0.6
Black screen (cd/m2)	1000	500
Screen contrast ratio	1111	833
Dark detail within image (cd/m^2)	4.6	33.9
Bright detail within image (cd/m^2)	587	367
Local contrast ratio	127	11
Coronis Uniti advantage in local contrast	12 times greater	

Figure 9: Higher local contrast with Coronis Uniti

The reflection of ambient light can vary enormously from display to display. The combined specular and diffuse reflection of the Optical Glass on Coronis Uniti is about one-third of that on other displays, as shown in Fig. 10:

% specular reflection by color	Coronis Uniti	Coronis Mammo
Blue	1.3 %	3 %
Green	0,7 %	2 %
Red	0,6 %	2 %

Figure 10: Optical glass reduces reflection

Reflection decreases the display contrast by adding some light to all the parts of the image, which more adversely affects the very dark parts. For this reason, the ACR recommends a minimum luminance ratio, rather than a contrast ratio, meaning the ambient reflection needs to be taken into account when calculating the ratio (Norweck et al., 2013).

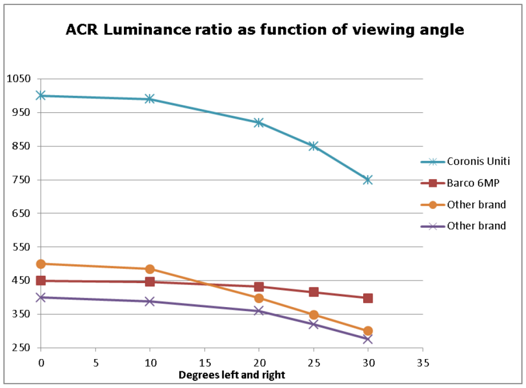


Figure 11: ACR “luminance ratio”

Using the ACR methodology, the Coronis Uniti has the highest luminance ratio of any medical display (Fig. 11). It easily meets the ACR minimum level of 350:1 over the entire field of vision.

Number of pixels

The number of pixels is directly related to the resolution of the image. The more pixels on a display screen, the more realistic and accurate the resulting image will appear. Radiologists should utilize a display with the highest number of pixels possible based on imaging modality and budget.

Medical physicists refer to line pairs per millimeter (lp/mm) when they discuss resolution. To understand this, picture an image covered with alternating black and white lines. The physicist is checking that the lines can be differentiated, and is measuring how closely spaced they are. For modern medical displays, this measure is still important as it directly relates to the capabilities of the human eye.

In the case of a display, where the image is formed by pixels, one line pair is equivalent to two pixels. To obtain what appears to our eye as a crisp image, 2.5 lp/mm is considered a minimum at a luminance of 350-600 cd/m2 (Norweck et al., 2013). And since acuity (how sharply we see) is proportional to the square root of luminance (Rose, 1948), with 1000 cd/m2, it makes sense to move to 3.0 lp/mm (0.168mm pixels). This prevents the artifact described in the ACR reference guide: "If the pixel pitch of a display is too large, a fine textured pattern is visible, and oblique edges have a staircase appearance" (Hirschorn et al., 2013). This effect can be demonstrated in Fig. 12, below:

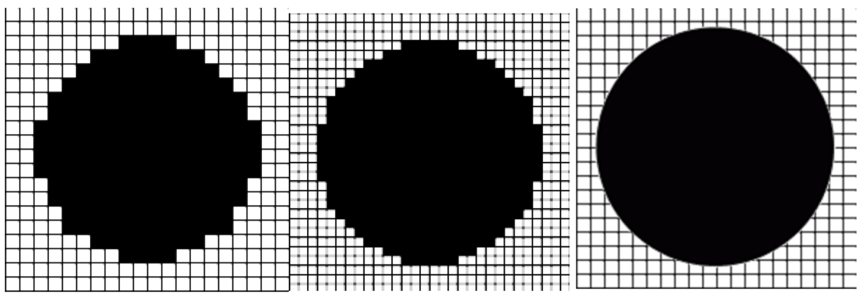


Figure 12: Smoother curves with more pixels

One benefit of more pixels per inch or line pairs per millimeter (lp/mm) on a screen is the ability to put more images on the screen with sufficient detail, or one image with more details. In both cases, the curves are smoother and lines are straighter, producing a more realistic image when more pixels are represented; in cases with insufficient pixels, the structure looks artificial.

The detection of small objects has been measured with the Contrast Detail Mammography (CDMAM) phantom for objects with a variety of sizes and subtleties (Bacher et al., 2006), as shown in Fig. 13. This shows that there is a substantial improvement when using 0.165mm size pixels. The Coronis Uniti, while having more pixels than a 5MP display, nevertheless has a similar advantageous pixel size of ~168 microns.

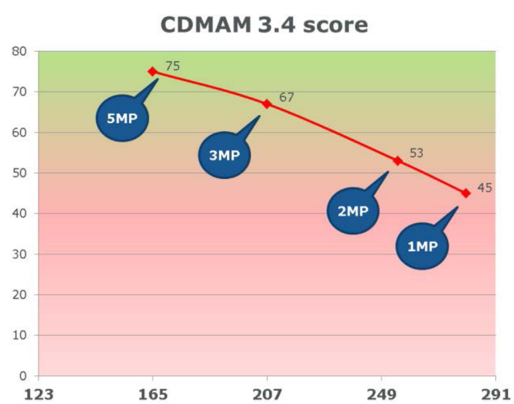


Figure 13: Contrast detail score increases with resolution

Amount and distribution of colors

Most human eyes can accurately see and distinguish colors. Color recognition is useful over the entire field of vision for drawing our attention; in the center of our vision, we can discern very subtle differences in hue and saturation. For medical displays, color should be both strong and consistent to best represent medical images.

Most displays do not have any color calibration, even when they are equipped with grayscale calibration. All too often, color scales look like the image on the left (Fig. 14), favoring certain hues and compressing others. The best approach is on the right, where all hues are more or less evenly presented. The Coronis Uniti provides color calibration, both to set the white point to match clear base or blue base film, but also to evenly distribute the colors.

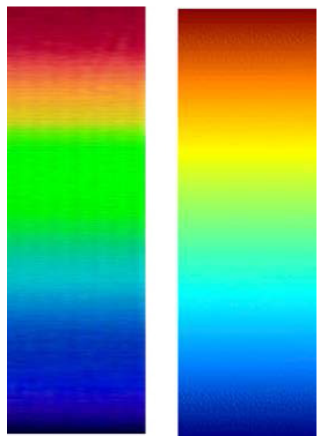


Figure 14: Spreading colors evenly

Color intensity is a function of perceived saturation. Using optical glass to prevent crosstalk in the colors and driving each color channel to a high luminance, it is possible to get a better sense of the relative shades of color in medical images. Fig. 15 below depicts two color cubes, with the smaller cube representing a typical display with ordinary LCD colors, and the larger cube representing the more powerful color present in the Coronis Uniti.

For a more complete treatise on color and color calibration, please see the Barco white paper on color calibration: *An Introduction to Color for Medical Imaging.*

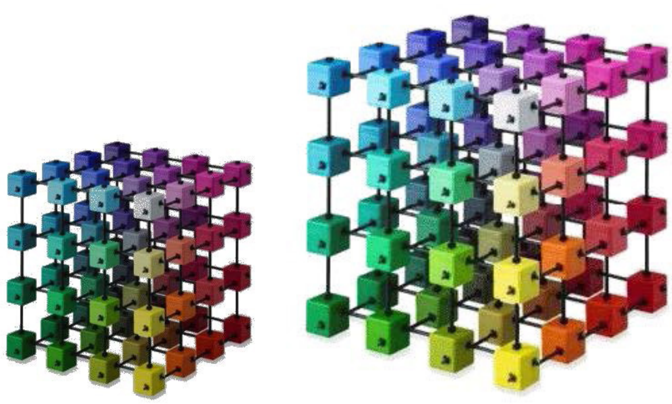


Figure 15: Vivid colors with high luminance

High and uniform luminance

Display luminance should be sufficiently bright and constant over time to create the sharpest image, while minimizing radiologist eye fatigue. There are several effects of higher luminance in the field of vision. Ergonomic benefits of more natural lighting in the reading room are covered in in Barco's paper on ergonomics and workflow and in other literature, but the visual acuity advantage can be described here.

Inside our eye, the flux of photons falling on different parts of the retina is what allows an image to be perceived. With more photons, smaller objects or details can be seen. The DuraLight Brilliance in the Coronis Uniti display provides more photons, emanating a steady, even light that produces a film-like luminance.

The likelihood that the eye can detect an object varies with luminance. As shown in Fig. 16, this has been calculated (Kimpe & Xthona, 2012) for small objects like calcifications, which demonstrates that even at the same contrast and size, objects in a typical medical background are much more readily perceived with higher luminance.

Luminance	Detection rate
500 cd/m^2 - typical diagnostic display	68 %
1000 cd/m^2 - Coronis Uniti	85 %
2300 cd/m^2 - Coronis Uniti with I-Luminate	94 %

Figure 16: Increased detection with higher luminance

The pupil size of our eye is affected by the display luminance, particularly the blue component of that light. A higher luminance decreases the pupil size, which in turn increases acuity of small objects and also increases the depth of field (Marcos et al., 1999), i.e., the range of distance where objects are simultaneously in focus. This makes it more comfortable to read images, as less change in focus is required. As depicted in Fig. 17, with a viewing distance of 65cm, the depth of field increases to 34 cm, resulting in a much sharper and more defined entire field of vision.

pupil size (mm)	near focus (cm)	far focus (cm)	depth of field (cm)
4	52	71	20
2	48	81	34

Figure 17: Smaller pupil increases depth of field in focus

The luminance of a medical display should be constant over time. Barco's patented I-Guard technology is a feedback system that allows each display to show the same image from one day or even one year to the next to enable a comparison between the current and the past appearance. It is also important that each display is uniformly bright over the surface, so that all areas are equal and comparisons can be made from left to right or between any two windows on the display.

LCD displays, LED backlights, even optical materials have some variations that cause non-uniformity. To overcome this in a fundamental way, each display can be measured and non-uniformities can be adjusted as part of the manufacturing process (Kimpe et al., 2005).

Luminance uniformity comparison with PPU OFF and PPU ON video level 512 measured on green

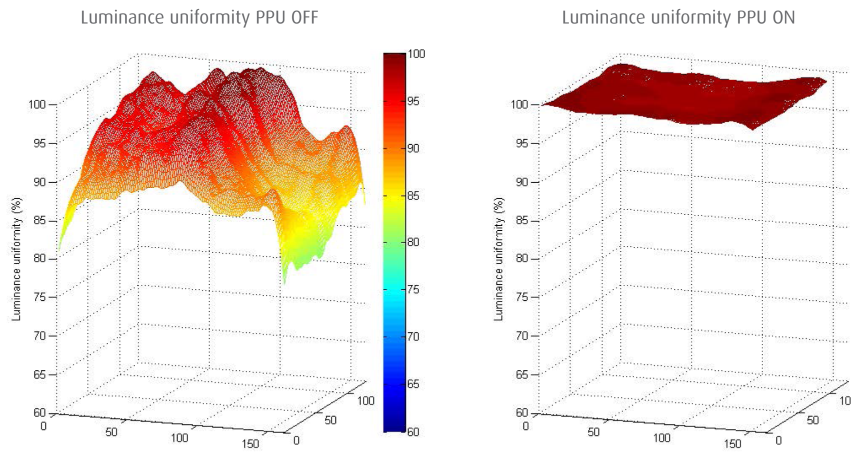


Figure 18: Uniformity is improved with Per Pixel Uniformity (PPU)

The Coronis Uniti utilizes the most precise method of adjusting the display, Color Per Pixel Uniformity (PPU). In the Fig. 18 above, PPU is used to greatly improve the display uniformity, largely eliminating noise that would otherwise be added by the display system. The result is that the entire field of vision is optimized, and a better contrast-to-noise ratio is achieved (CNR). The positive effect of PPU was also measured and found to increase the scores for the CDMAM over 6% (Bacher et al., 2006).

Viewing Angle

With multiple displays, each one can be tilted to face the viewer. But, how does the image vary with viewing angle on a single display? A single display cannot be folded or curved to compensate for potential viewing angle distortion. For this reason, Barco Optical Glass is employed on the Coronis Uniti to ensure that viewing angle differences do not adversely affect the field of vision.

Two aspects are important to consider: reflectivity increases and contrast diminishes with viewing angle. As indicated in Fig. 19, because the Optical Glass has a much lower reflection, the specular reflection is much lower even though the maximum angle of regard increases slightly compared to a pair of angled 5MP displays.

	Angle of regard to farthest corner	Specular reflection
Coronis 5MP	23 degrees	2.2 %
Coronis Uniti	33 degrees	0.9 %

Figure 19: Low reflection even at display corner

The contrast ratio advantage achieved with the combination of the Barco Optical Glass and LCD panel can be illustrated by placing the contrast plot of a pair of 5MP displays on top of the contrast plot of the Coronis Uniti (Fig. 20). A good medical display has at least 900:1 contrast when viewed straight on; this is the angle zero. Similarly, displays are characterized by their half-contrast angle. This would be the viewing angle that can be used while still maintaining a 450:1 contrast ratio.

In the figure, both systems cover the +/- 30 degree circle of vision where we can see shapes and colors. The Coronis Uniti has 900:1 contrast over that angle. Even with a slightly higher angle of regard to the corners, the contrast in the field of vision is twice as high.

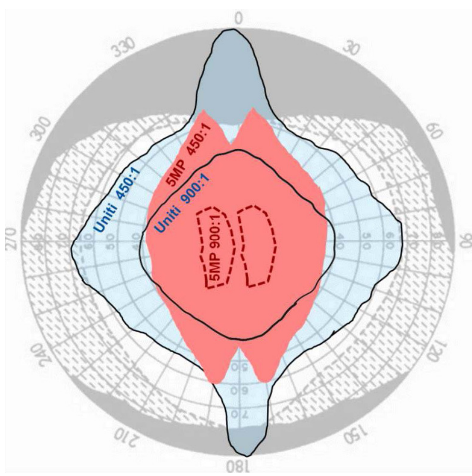


Figure 20: High contrast not limited to center

The acuity chart below (Fig. 21) captures the combined advantage that luminance, local contrast, and viewing angle have on the field of vision. This chart plots the just-noticeable threshold for objects with average pixel value 300/1024. It uses the contrast sensitivity function of the human eye (Van Nes & Bouman, 1967) and shows how small an object can be detected, depending on how much the object contrasts with the background. Objects below the line are not perceived, and objects above the line are increasingly obvious. With the same image data, the Coronis Uniti can make smaller and more subtle objects visible that would otherwise not be seen.

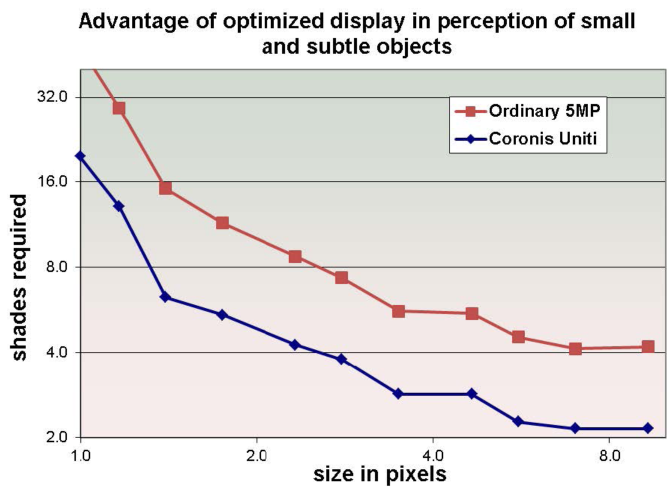
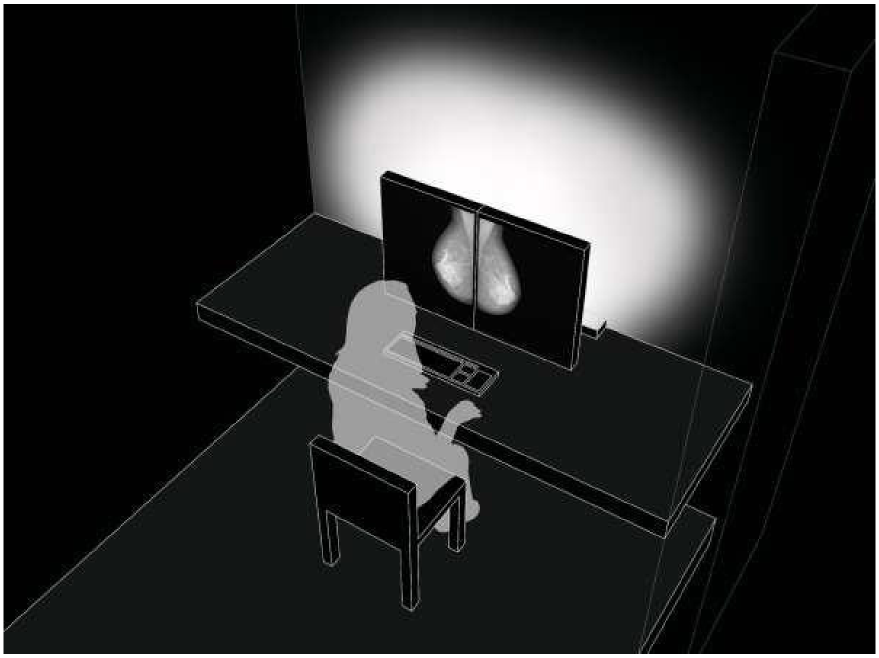


Figure 21: Smaller and more subtle objects visible



Conclusion

4. Conclusion

The quality of images in the radiologist's field of vision is an important criterion in the selection of a medical display to optimize performance, diagnostic accuracy and radiologists' comfort during image reading sessions. By designing the ideal display form factor as well as enhancing display parameters, such as local contrast, color, luminance, and viewing angle, Barco has created a diagnostic imaging solution that optimizes the reading experience. The result: enhanced productivity and less occupational stress and strain for the clinician.

The field of vision has an extent of +/- 30 degrees; within this range, shapes and colors can be readily observed. The most comfortable portion of this area is limited to near eye-level and below, suggesting an ideal size for a medical display.

The Coronis Uniti has been designed to fill this field of vision, featuring vast real estate to prevent the need for auxiliary diagnostic displays. The fusion format eliminates distracting bezels and allows the valuable space in the middle of the field of vision to be used for image data. Studies show that a bezel-free widescreen display can increase radiologist productivity by enabling them to read faster, with less eye strain.

To optimize the field of vision, every aspect of the display image quality has been specifically designed for the task.

- Barco's Optical Glass reduces blurriness.
- Local contrast has been dramatically improved, making the image contrast of real images up to 12 times higher than before.
- Reflections have been reduced by a factor of three, making the display more tolerant of ambient light.
- Spatial resolution matches that of a 5MP display, allowing optimum perception of fine details, not only for mammography but also for challenging radiology work.
- Calibrated color provides repeatable, evenly spread colors that are bright and vivid.
- Improved detectability of objects is achieved by the combination of stronger signal and lower noise, resulting in an improved contrast-to-noise ratio, thanks to two proprietary features: DuraLight Brilliance and Per Pixel Uniformity.

With the Coronis Uniti, radiologists can optimize their diagnostic image reading experience by utilizing a display that is tailored to their visual "sweet spot," with features that are optimized to deliver the best image quality. Featuring the latest in imaging technology and ergonomic design, the Coronis Uniti is the ideal choice for managing the myriad of studies and images that make up the busy day of any radiologist.

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