White Paper

Medical displays give radiologists an edge

What's inside?

- What is the difference between dedicated medical displays and commercial off-the-shelf displays?
- How different are their feature sets?
- What is the impact on radiologists' performance?

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ABSTRACT

Medical displays have been proven to contribute to improved diagnostic accuracy for cancer detection, especially as compared to commercial off-the-shelf displays. This is due to improvements in viewing angle, longevity, luminance, and noise reduction, resulting in substantially superior accuracy and effectiveness.

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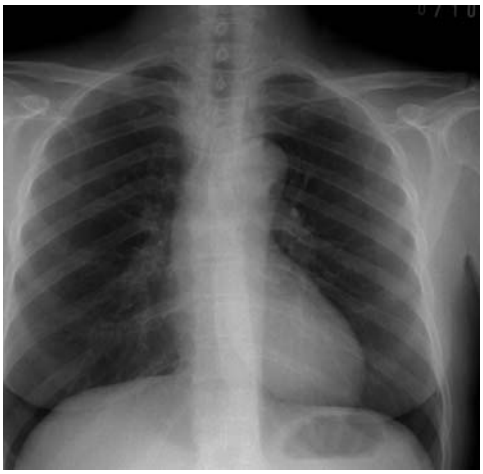
1. INTRODUCTION

Commercial off-the-shelf displays have some of the characteristics that are appropriate for review and diagnosis of medical images, but they lack others, which should be of concern to the radiologist: “The physician performing the official interpretation must be responsible for the quality of the images being reviewed and understand the elements of quality control of digital image management systems” [ACR 2007]. This paper first discusses some of the technical characteristics of medical displays that allow optimum interpretation performance, such as stable contrast from all angles, high luminance maintained over time, noise reduction, and lookup table accuracy. It will then present some results from a recent study by Krupinski [2008] showing that these attributes lead to significant, measurable differences in radiologist performance.

2. STABLE CONTRAST FROM ALL ANGLES

The data sheet of a commercial display may report very high contrast, sometimes even higher than some medical displays. However the response of the commercial display is very dependent on the viewing angle [Badano 2003], so in this respect, performance is not consistent. This is illustrated in the chest image (below left) which had the window and level set for lung nodules. In the second image, the distortion introduced by an off-center viewing angle has emphasized the bone detail at the expense of the lung detail.



On-center

Off-center

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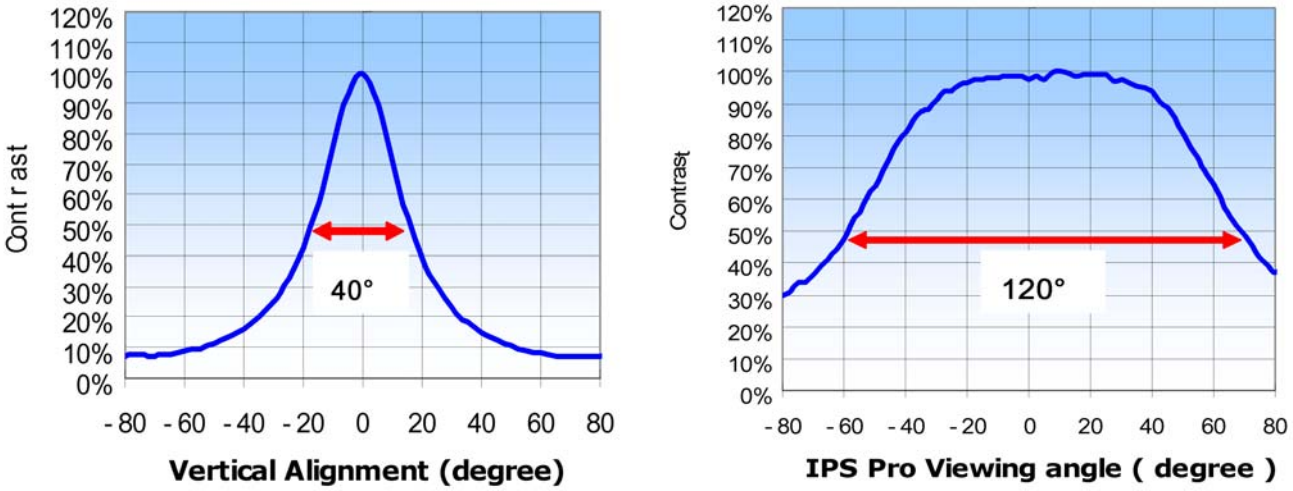
When contrast varies with viewing angle, the detection ability of an observer changes as the angle varies [Krupinski 2005]. Medical displays utilize a special kind of liquid crystal process, *In-Plane Switching* (IPS). Commercial displays use a less-expensive type of liquid crystal process, *Vertical Alignment* (VA), one that is tuned specifically for on-axis viewing (and gives those high numbers on data sheets). In other words, when you look right at the center of a commercial display, it has very high contrast, but the contrast drops off rapidly as you change your angle to view either the corners of the display or a second display off to the side. Medical displays maintain high contrast over a much larger angle. The diagram below shows the effect:



In fact, since 2007, commercial displays have increasingly switched toward an even-less appropriate LCD technique known as twisted nematic (TN). This technology is older and had been largely been discarded. Recently though, as cost pressures the commercial displays, they have started using it again.

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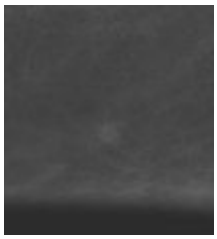
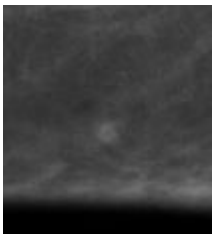
3. HIGH LUMINANCE MAINTAINED OVER TIME

Medical displays are engineered to provide a very high luminance. While ACR guidelines call for a minimum luminance of at least 250 cd/m^2 [ACR 2007], it is readily apparent that brighter displays make subtle objects easier to resolve. Even when using a panel set at a particular contrast, the perceived contrast will increase as the luminance increases. This is because the human eye works better with more light. Below is an illustration of the difference in the way a subtle mass appears on a commercial display and on a medical display. In both pictures, the same information is present in the image data, but there is higher contrast in the appearance on the medical display.



Commercial



Medical

This improvement of image appearance with increased luminance manifests as less time spent searching: “lower-luminance levels prolong the search and recognition of normal, lesion-free areas compared with lesion-containing areas”. [Krupinski 1999]

Stability is another important factor. Luminance variations on a typical Barco medical display are controlled by built-in hardware feedback mechanisms, including backlight output stabilization (BLOS) and/or an I-Guard precision photometer. The luminance is set at the factory to 500 cd/m^2, and is guaranteed to remain at that level for at least five years.

Unlike medical displays, commercial displays change over time since they lack feedback mechanisms to regulate themselves. As a result, one of two things must be done: the displays could be used for a short while and then recycled, or the displays must be routinely calibrated by a technician or IT staff person.

The diagram below shows the aging of a set of 10 commercial displays actually used in a hospital in Georgia. It is clear that there is quite some variation after one year’s time.

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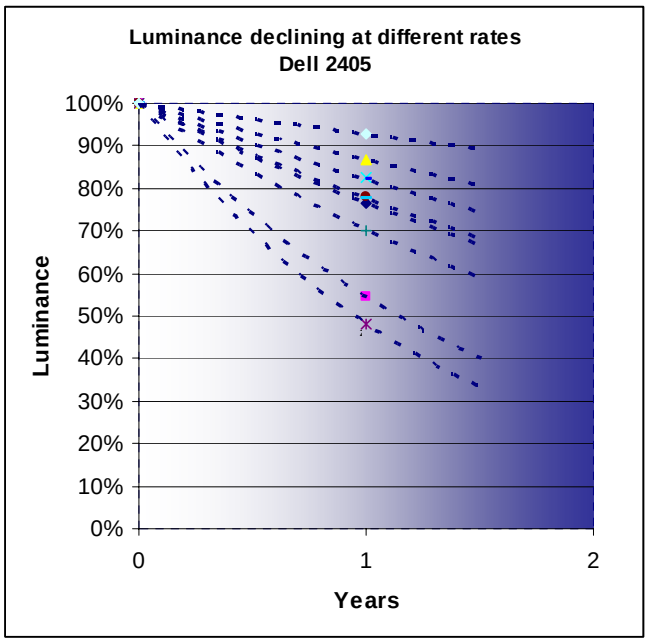

No radiologist would tolerate a situation where some seldom-used displays are still running at 80-90% of the original luminance while others are running at 40-50%. When using commercial displays for radiology there is an additional burden of frequently checking all the displays, retiring some, and adjusting others.

4. NOISE REDUCTION

Noise reduction is another way in which medical displays stand apart from commercial displays. All LCD displays, indeed all displays, exhibit some variation across their surface. LCD cells transmit and modulate the light produced by the backlight. Each cell is formed slightly differently, and so has different transmission characteristics. These differences manifest as noise.

Obviously, noise is bad and if the noise can be reduced the display will look better. There is also a clinical impact. Below, the initial non-uniformity contains several types of noise. In terms of characteristic frequency, there are both low and high frequency components. The low frequency component makes comparison between two areas of the screen difficult, as one area will be darker than the other. The high frequency component adds noise to detection tasks (i.e. discerning edges and textures). But this spatial noise goes beyond the quantum mottle present in x-ray images; it has patterns similar to anatomic noise. And this type of noise is much more disruptive to the diagnostic process than quantum mottle [Samei 1999]. By applying a correction for the

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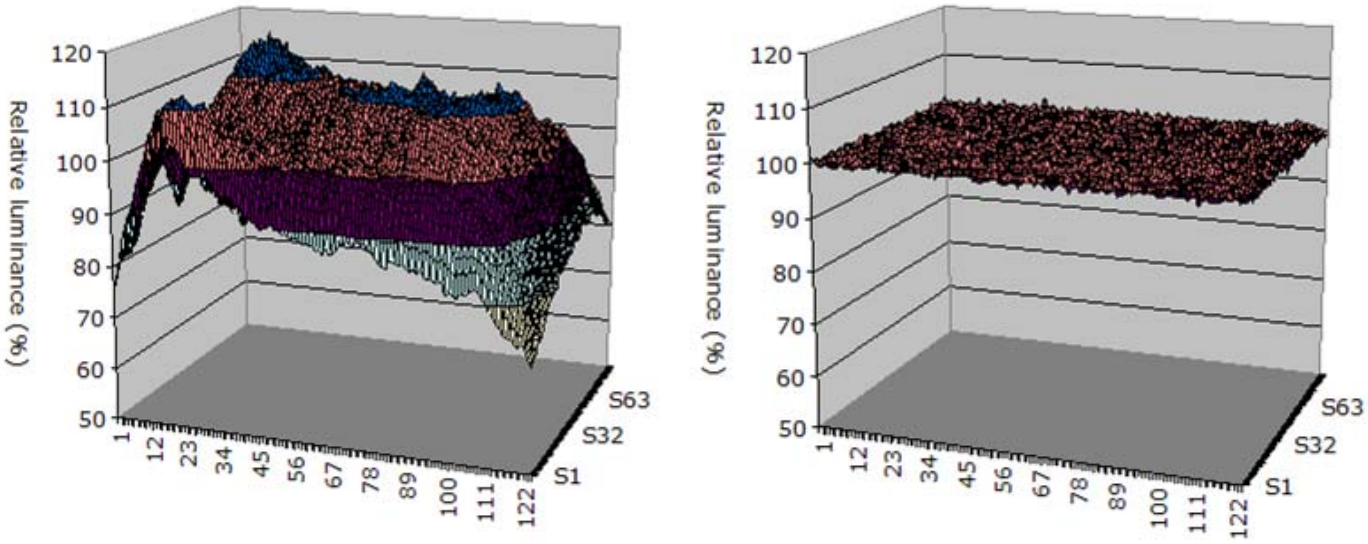
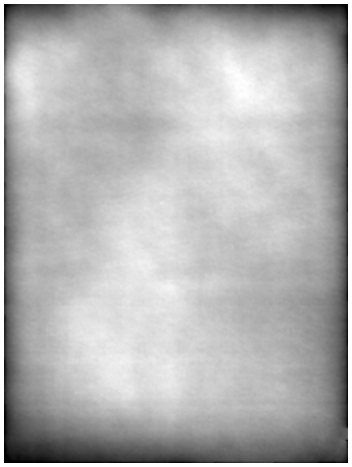
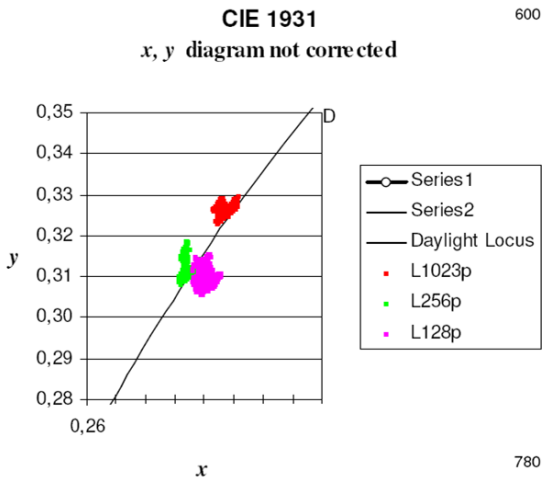
spatial noise, medical displays with uniform luminance technology eliminate all but a small amount of noise, and what noise remains is similar to a low level of quantum mottle. [Kimpe 2004]



In addition to luminance variations, shown in the exaggerated gray image on the left below, there are color variations. As the display is made up of red, green, and blue sub-pixels, it happens that one area of the screen will have a different color temperature than another area. Simply put, both luminance and color variations are errors, and will introduce noise into the display.





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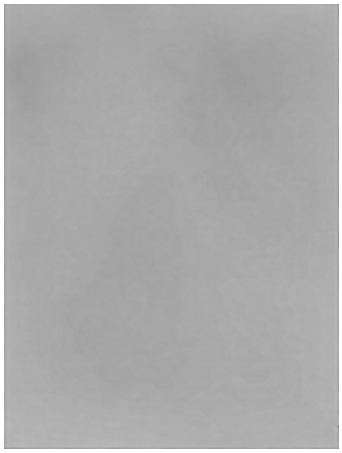
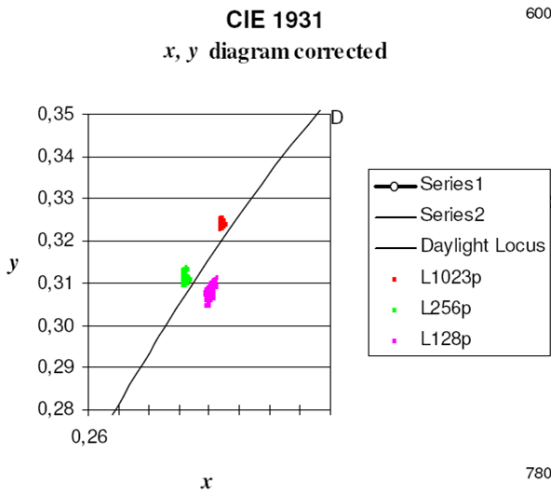
On a typical commercial display, there can be variations of up to 30% in the luminance.

Consider the improvement with a medical display shown below. The error in color is greatly reduced over the surface of the screen, as is the error in luminance.





Lookup table accuracy:

The lookup tables (LUTs) in a medical display system serve to allocate the various luminance levels across the range required by the image. Ideally, this allocation is done evenly so as to perceptually optimize the visibility of all medically relevant details. On a display that has color, the LUT also serves to allocate the chrominance range, often to emphasize some aspect or to map an additional dimension of data such as functional activity. For both the luminance range and the chrominance range, it is essential that the mapping be done both with sufficient precision and in a consistent way. Imprecise mapping leads to aliasing on the edges of objects, the appearance of contour lines in the image, and a more grainy appearance. Unlike commercial displays, medical displays evenly allocate the luminance levels across the entire range of the image.

In any display system, there are several stages through which the data passes, and during each stage it can be handled with more or less precision. If there is more precision in one stage than is required, no harm is done. But if one or more stages constrict the data, then some precision is lost on the way to the eye. In a medical display system, the data passes through stages of essentially constant precision as seen below. In each stage at least 10-bits of precision are preserved. This is possible because limiting elements of off-the-shelf technology have been replaced by specially designed components that can preserve the full fidelity of the medical image. In contrast, because the standard DVI transport in commercial displays allows only 8-bits per color channel, the pipeline is constricted to 8 bits from that point forward.

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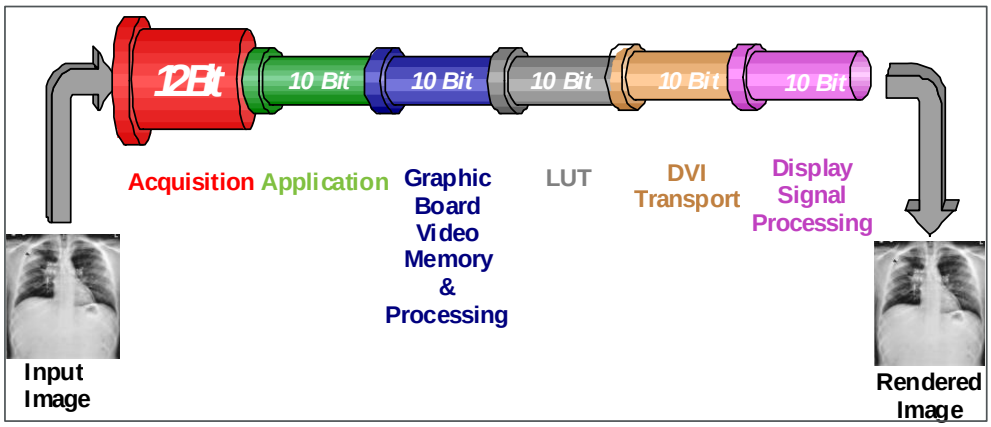

Medical display system using at least 10-bit precision for all parts

5. MEDICAL MONITORS RESULT IN MORE ACCURACY BY RADIOLOGISTS

Clearly medical displays are engineered for optimized viewing of medical images. But is there any evidence that these characteristics lead to better results? Over the past few years, various people have considered that perhaps commercial displays could be set up carefully and then used for radiology. In particular, Dr. David Hirschorn has suggested that his results support this. Here is one such claim:

> The medical grade and the Dell consumer monitors produced the same findings in 117 of 121 cases. Two fractures and one kidney stone were seen on the gray-scale monitors but not seen on the Dell 2405s. In 11 cases, other findings that were seen on the Dell 2405s were not seen on the gray-scales. However differences were not of any statistical clinical significance. "These results don't prove that you can use this display, but there is a good chance to believe this is probably reasonable," Hirschorn said. "In practice, a lot of radiologists use this setup and are comfortable using this system for primary interpretation of radiography." [Hirschorn 2006]

People have identified several problems with this study. Failure to have statistical power to find a difference does not prove that there is no difference. It could instead be due either to a high variance or to too small a sample, in other words, a study design that lacked the ability to measure the difference. The displays were brand-new, so no aging had taken place. Also given the high rate of true positives, it seems that the targets presented were easy to spot, rather than subtle. Commercial monitors may well be good enough to find obvious cases; one would expect medical monitors to outperform them mainly with the challenging cases.

Despite these problems, it does raise a good question: Are the commercial displays getting to be good enough?

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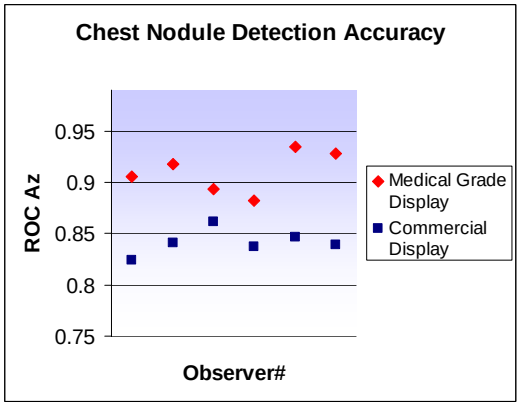
There are various well controlled studies demonstrating that differences in certain parameters like resolution and luminance certainly do affect radiologist performance [Bacher 2003, Krupinski 2007]. The recent, well-controlled study by Dr. Krupinski [2008] compared detection of pulmonary nodules by radiologists using a 3MP Barco color medical-grade display vs. the same commercial display that Dr. Hirschorn used in his study. In this study, challenging cases were presented with subtle nodules that would be hard to see if conditions weren't right. The overall accuracy was expressed as the area under the receiver operator characteristic curve (ROC A_z) which addresses inaccuracy resulting both from missed cancers and false positives. As can be seen in the graph below, every radiologist observer found the medical displays to give more accurate results. The results confirmed the common sense notion that with better displays, radiologists perform better.



6. FASTER READING SAVES MONEY

Even though the purchase cost of medical displays is higher than commercial displays, the professional solution is less expensive, even after only one year of use. Studies show that radiologists come to the correct interpretation more quickly with medical displays [Bacher 2003, Krupinski 2008]. In particular, both studies indicate that there is more certainty with the better displays as found in the lower number of false positive and less time spent on viewing them. Below is an example calculation of the financial impact:

Facility data:	
Number of new displays to purchase: (COTS or medical display)	1
Number of studies per year:	15,000
Period:	5 years
Cost of radiologist per hour:	$295

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ROI model data:	
COTS display cost:	$1,200
Medical display cost:	$7,000
Time to read image on medical display:	35.17
Time to read image on commercial display:	37.99
Faster reading an image on medical display versus a COTS display:	2.82
Faster reading an study on medical display versus a COTS display:	5.64

Calculating the savings from the faster radiologist and balancing this against the cost of the money used to buy the equipment gives a very positive net present value and a good return on investment.

COTS display investment:	$1,200
Medical display investment:	$7,000
Radiology yearly cost reduction if medical displays are bought:	$6,933
Reduction for whole period:	$34,663
NPV:	**$23,009**
ROI:	**4.98**

This result is presented in the graph below. A prudent skeptic would ask how sensitive the results are to the cost of the radiologist, cost of the commercial display, etc. Because of the high price of radiologist time, the model is relatively insensitive to the cost of the commercial displays. In fact the graph below looks very similar if the commercial display is free.

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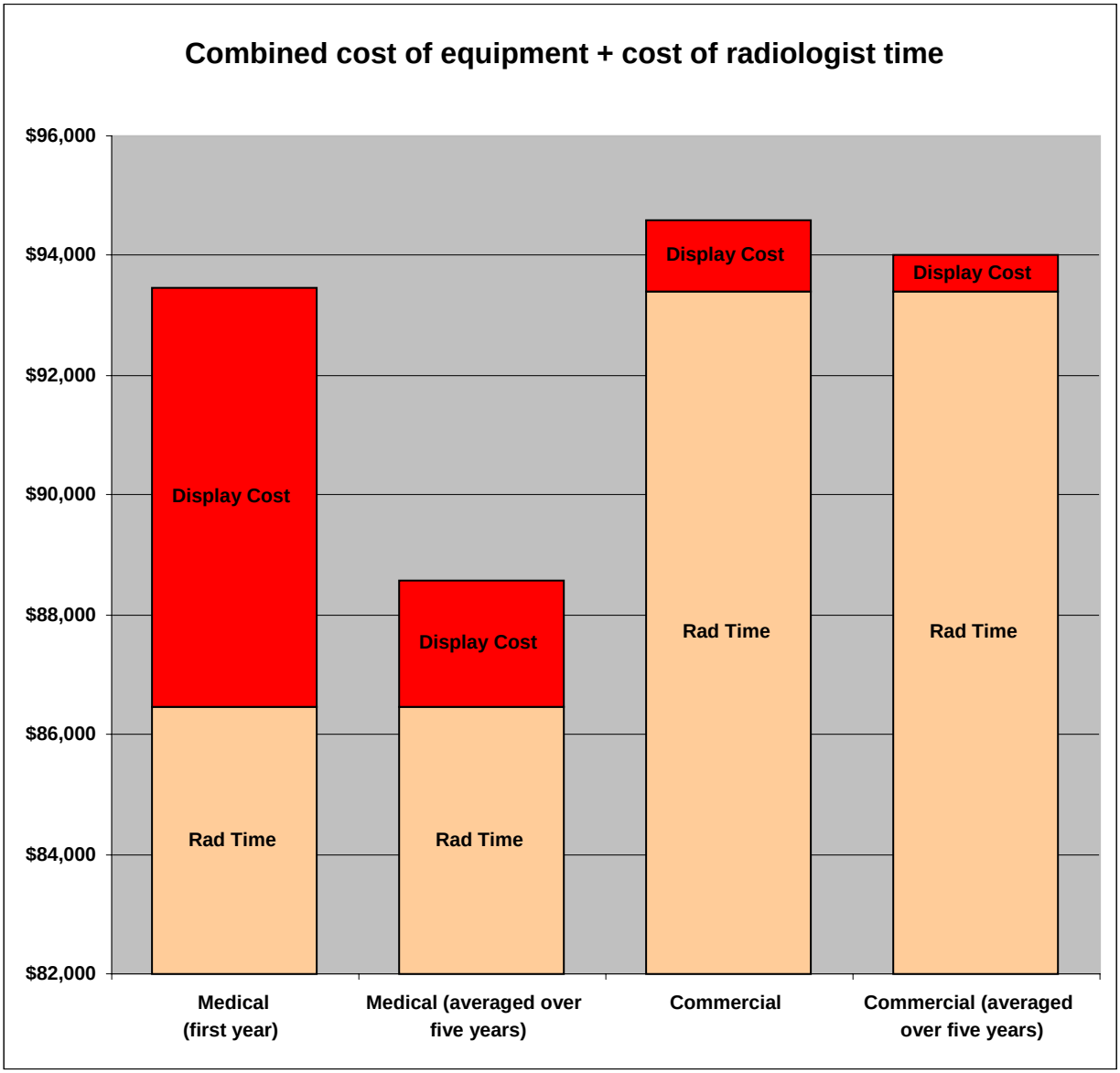

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7. CONCLUSION

Implications of reduced detectability are substantial: the increased dose required to overcome noise for example increases the risk to patients that is posed by any exam utilizing ionizing radiation. This relationship between detectability, noise, and dose has been extensively studied and continues to be an area of enormous concern. [Bacher 2006] [Samei 2007]

There is a substantial difference between dedicated medical displays and commercial off-the-shelf displays, both in terms of radiologist performance as well as in terms of feature set. The table below summarizes this difference.

	Medical Display	**Commercial Display**
Contrast stable over useful viewing angle	Yes, uses IPS LCD	No, uses VA or TN LCD
Luminance at 1 year	500 cd/m^2	<250 cd/m^2
Lifetime at factory settings	5 years	1 year maybe
Noise reduction	Uniform Luminance Technology	None
LUT precision	10-bits minimum	8-bits
Accuracy	91%	84%
Faster interpretation	Yes, with higher certainty	No

The value that the medical display brings to radiology goes beyond the improvements in accuracy of diagnosis of subtle cases. Medical displays are designed from the beginning to be exactly what a radiology practice needs:

- Grayscale on color displays: convenient for all imaging studies
- Controlled start-up conditions: saving time and allowing reduced power consumption
- Built-in calibration: minimal staff time spent on adjustments
- Knowing that everything is OK: priceless

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Klaus Bacher, Peter Smeets[2], Ludo Vereecken, An De Hauwere[1], Philippe Duyck, Robert De Man, Koenraad Verstraete and Hubert Thierens *AJR* **2006**; 187:630-637

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