# Designing the Perfect Reading Room for Digital Mammography

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## 1. INTRODUCTION

Millions of women are screened for breast cancer every year, resulting in tens of millions of x-ray images that need to be read. The reading rooms that are used vary greatly, and many radiologists express concern about the conditions in either their workplace or the workplaces of their colleagues. Now that softcopy mammography screening is becoming commonplace, there is an opportunity to revisit the mammography reading room.

This white paper describes how to design a mammography reading room that will give the best results for screening digital mammograms: Goals of the mammography reading room are covered first, then the design of the work environment. After examining the contrast of mammography film, an explanation of the immense importance of ambient light control follows. Then the relationship between contrast and viewing angle for film and LCD displays is discussed and shown graphically. After a brief discussion of quality assurance, a checklist is presented that can be used in the process of planning a perfect reading room.

## 2. KEY GOALS - WHAT DO YOU WANT TO ACHIEVE?

There are several goals for the mammography reading room:

- Read a large number of exams each year. This high productivity implies an efficient workflow – low time per screening, and fast turn-around time. "Radiologists surveyed agreed that three variables had the greatest effects on their productivity: ambient lighting, monitor brightness, and the number of monitors available".[1]
- Find as many of the breast cancers as possible. This is a classic detection problem: find and characterize subtle objects in x-ray images. The factors that largely determine the success of this detection are radiologist experience, contrast, and spatial resolution.
- Provide a comfortable work environment for the radiologists.
- Instill confidence in the quality of the work. The confidence of the public is very important, as women are more motivated to go to a screening exam if the reputation of the screening center is good. The confidence of colleagues and government agencies can also be important. A quality assurance process can ensure known quality, a good reputation, and repeatable results.

[1] Optimization of Filmless Radiology Room Design: Survey Results of Experienced PACS Users. Eliot Siegel et al., June 2000.


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## 3. ENVIRONMENTAL DESIGN

Mammography is a specialty of radiology. In many countries, additional certification is required and this certification is based on reading a large number of exams each month. For this reason, it is common to find radiologists working in a "production environment", where they will screen exams for an hour or more without a break. Additionally, it is important that they work in a comfortable environment. The radiologists should be able to work undistracted so that all their attention can be focused on fast and accurate screening of the exams. Typical office ergonomic requirements cover much of what should be done to make the room comfortable.

- The chair-table combination should be such that the eye-level of the radiologist can be brought up level with the top of the image[2]. Because radiologists frequently zoom in on the image of the breast, by moving their head closer, and as the softcopy image is 400mm high or more, this requires a fairly adjustable chair.
- Noise can be controlled by several means. Some models of computers are quiet; others might have to be located behind a partition or wall. A typical office environment may have ambient noise of 50 dB, but it would be best to target a maximum of 45 dB for a room where concentration is so important. Acoustic tiles on the ceiling and carpet on the floor are traditional sound absorbers. Air handling systems should be ducted with large cross-sectional ducts to keep the velocity of air low. The door should be set to close quietly. Ballasts for all lighting should be inaudible. The addition of quiet music is a possibility depending on the preference of the radiologists, but this is no substitute for noise elimination.
- The temperature of the room should be well regulated and individually adjustable from within the radiology suite. It is not typically practical to provide for a temperature that is individually adjustable at each workstation. An effort can be made to ensure that the entire room has sufficient airflow and a constant temperature throughout.

What is the ideal arrangement of this comfortable room? While not necessarily the most aesthetically interesting, consider the rectangular room below.

[2] OSHA Publication 3092, 1997.



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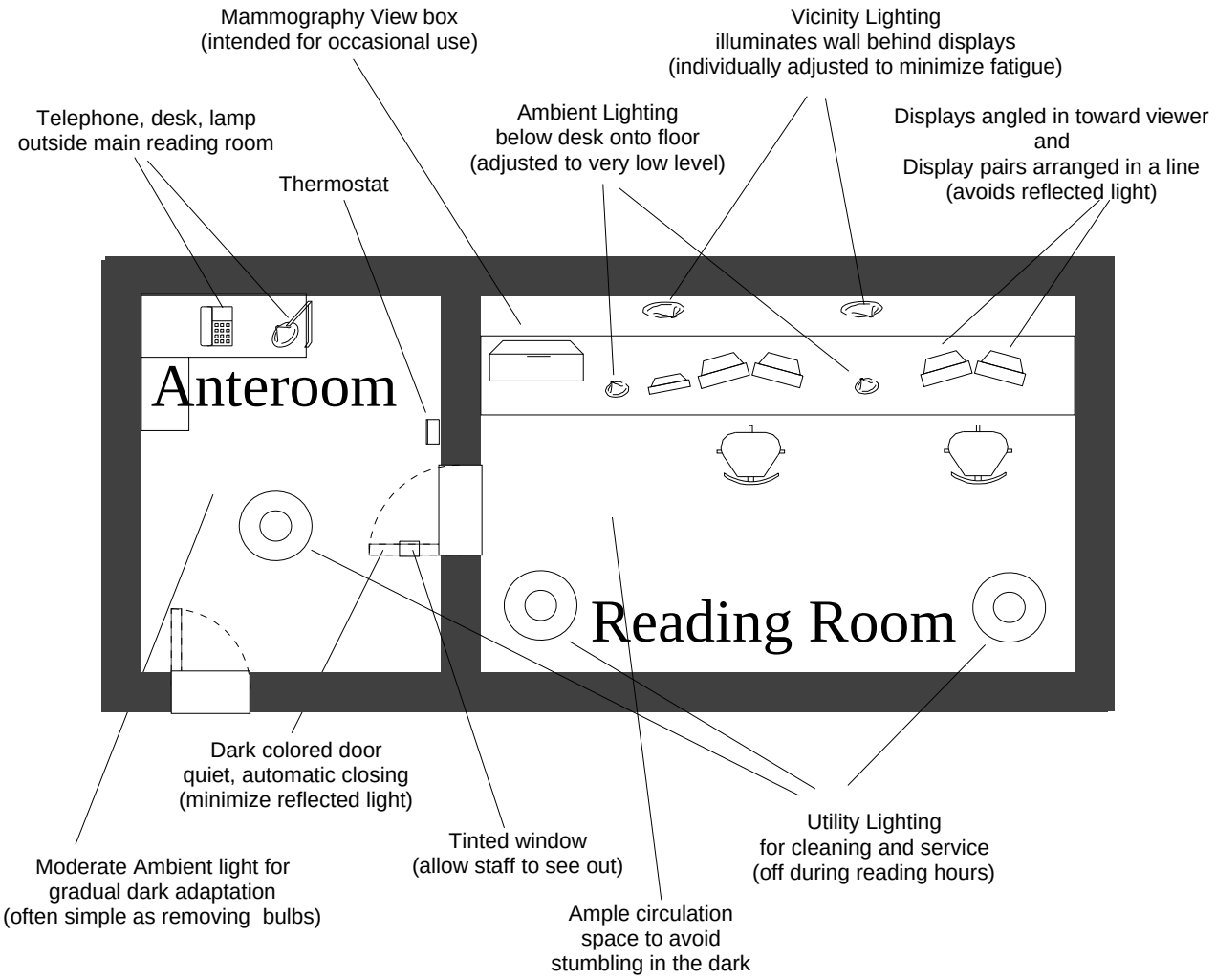


**Diagram 1 – Mammography Reading Room Space Plan**

This design is constructed around the need to control light, and the desire to provide a comfortable work environment.

- The two or four diagnostic displays should be “angled in” or aimed at the radiologist. This provides for the maximum contrast: The viewing angle is as close to straight-on as possible. Also, near-vision deficits are avoided as the distance to all parts of the displays are more or less equal.
- Multiple workstations are arranged in a single line. There is an important reason for this. If the light from another display falls on the display in use, it will dramatically reduce the contrast of that display. For the same reason, if a view box for film is included, this must be in the same line as the softcopy displays. No table is provided on the opposite wall; this eliminates the temptation to place additional light sources behind the radiologists.


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- Ambient lighting is arranged so as not to shine on the displays. Consider why people want ambient light. In addition to wanting to see who else is in the room, most people want to be able to see where they are walking. Aiming the ambient light down at the floor from under the desk is one way of making sure that people can find objects that have been dropped and that they can find their way around the furniture. A flashlight or torch can be useful in a dimly lit room, if the light is filtered with either a green or a red filter. Use of a green[3] filter will provide for the most excitation of the cones and the minimum excitation of the rods. This will best preserve the dark adaptation in one's peripheral vision.
- Vicinity lighting is provided to illuminate the wall behind the displays. This illumination serves to minimize the fatigue of looking back and forth between dark and bright. It should be controllable from each work area.
- Utility lighting is required for cleaning and service. This should provide illumination identical to other areas in the facility. It is important to that this lighting be on a separate switch plate. It should be very unlikely that the overhead lights are turned on accidentally during working hours.
- An anteroom is provided for several reasons. The illumination in the anteroom should be moderate – in between the nice bright typical healthcare environment and the very dark reading room. It can often be as simple as taking out one of the bulbs in the overhead lights. When passing in and out of the reading room, this moderate lighting helps acclimatize the radiologists' eyes. The anteroom also contains a telephone, desk, and spare chair for incidental use. The very low illumination in the actual reading room makes it difficult to read and write notes, etc. The anteroom also has a thermostat for the reading room, as it is often important to have local control.
- The door connecting the anteroom to the reading room should be designed to close automatically. This way when someone leaves in a hurry, no one need get up and face the light in order to close the door. Painting the inside of the door a dark color will reduce the amount of light that bounces into the room when the door is opened. A tinted glass window allows the staff inside to see out as they prepare to open the door.
- In the example above, two softcopy workstations are shown. More stations could be added, simply make the room as long as is needed. When adding more softcopy stations, keep them all in a line along the same wall. One of the workstations shows a navigational display. It is sometimes a challenge to get this display dim enough, especially if the software running on it uses bright white window backgrounds. If this is a problem, try turning down the brightness.
- Walls should be a fairly dark color. It is better to make them too dark and have to add ambient light, than to start with walls that are too light a color. Many people are happy with a yellow or orange-yellow paint color for the wall behind the displays. A carpet absorbs both sound and light. The carpet should not be so thick that it is difficult to roll around on the chairs.

[3] Most people expect a red filter. It may be easier to use red than to explain about relative cone sensitivities.


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## 4. CONTRAST RATIO OF MAMMOGRAPHY FILM

The characteristics of mammography film relate very strongly to the ergonomics and design of mammography reading room. There is widespread acceptance of the quality of mammography film. So if film is good, film-like quality is a minimum goal for softcopy reading.

Soft-copy displays are measured with contrast ratio; mammography film is measured with optical density. Contrast ratio is the luminance of the brightest white on the image divided by the luminance of the darkest black. Softcopy display systems are commonly measured with contrast ratio. The contrast ratio of mammography film is about 1000:1. This contrast ratio is much higher than the film used for other exams, e.g. Chest film.[4] In x-ray film, high contrast ratio is achieved by having a high optical density (OD). Optical Density is measured on a log scale; it is measuring the light absorbance. The contrast ratio can be easily calculated as $10^{(OD_{max} - OD_{min})}$. While mammography film has an inherent $OD_{max}$ of 4.2, the useful film latitude is somewhat lower. To avoid fog at the low OD, a minimum value of 0.5 is often used; likewise, a maximum value of about 3.5 is used to stay in the linear portion of the film. The contrast ratio of correctly exposed mammography film is thus $10^3$, or 1000:1.

| Film Type | Useful $OD_{min}$ | Useful $OD_{max}$ | Film Latitude | Contrast |
|---|---|---|---|---|
| Chest | 0.5 | 2.8 | 2.3 | 300 |
| Mammography | 0.5 | 3.5 | 3.0 | 1000 |

Why do Mammography films have such high contrast range? Low contrast masses are difficult to detect. Consider a mass with absorbance that differs from the surrounding tissue slightly. If this slight difference can be amplified, it is easy to detect. This effect is well quantified in the concept of Just-Noticeable-Difference (JNDs)[5]. Because our eyes can adapt to a wide range of brightness, we have the ability to increase our sensitivity to a particular range of luminance. The limit of this ability is the Just-Noticeable-Difference. Even though you take plenty of time to adapt your eye to a certain range, a sufficiently subtle difference will not be detected. For this reason, the perceived contrast of a subtle object is greater when the overall dynamic range of the object in increased, as shown in Diagram 2.

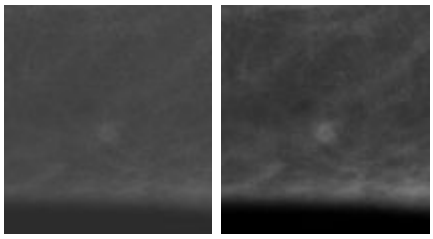

**Diagram 2 – Same object is more detectable when overall image contrast is higher.**

Why aren't other types of x-ray film made to have an OD similar to that of mammography film? There are a few reasons: Firstly, the higher the OD, the more silver is required. Additional silver requires more x-ray exposure and makes the film more expensive. Secondly, mammography radiologists need the additional contrast range to do a good job. Lastly, the

[4] Film commonly used for chest x-ray exams has a OD of 3.2, and is generally calibrated between 0.5 and 2.8.
[5] ACR-NEMA Gray Scale Display Function Standard



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mammography image has a very low average luminance, making it possible to look at both very light and very dark area of the image without lengthy adaptation.

## 5. AMBIENT LIGHTING

Ambient light is the single most important factor in productivity.
The Mammography Quality Standards Act (MQSA) requires that ambient light should be kept to a minimum in the room where images are evaluated.[6]
Since the goal is to facilitate detection of faint signals, the ambient illumination should be low, particularly when using older CRT displays. Some especially demanding standards recommend levels as low as 2.7 lux (0.25 ft-c)[7]. While this might be very nice for the image quality, it does make the room hard to work in. Why does a reading room with softcopy displays have more stringent requirements than a reading room with traditional view boxes? LCD displays and especially CRT displays are more sensitive to ambient light than mammography film on a light box. The view box is much brighter; it can overpower a certain amount of ambient light. Still, the effect of ambient light on a view box is substantial, and this is why reading rooms are traditionally very dark.

In graph 1 below, the greater sensitivity to ambient light of the LCD is shown. With ambient illumination above 10 lux, the LCD starts to have a lower and lower contrast, making the black level brighter than that of typical mammography film on a view box. A reasonable level of ambient illumination for the perfect digital mammography reading room is approximately 5 lux when using displays of 500-600 cd/m2. With brighter displays, proportionally more ambient illumination is appropriate. The wall behind the display (vicinity lighting) and the lighting directed at the floor both contribute to this total. The light level should be measured with a light meter (illuminance meter) to obtain an accurate number. When measuring the ambient light with an illuminance meter, the meter should be held flat on the surface of the display, aimed out toward the radiologist. The meter integrates light from all directions. Some displays include an illuminance meter. If the built-in meter has an integrating hemisphere, then it will be able to collect light equally from all directions.

[6] Mammography Quality Standards Act, 42 USC § 201:262b Pub L No. 102-539 (1992)
[7] MIL-STD-1472F, 1999


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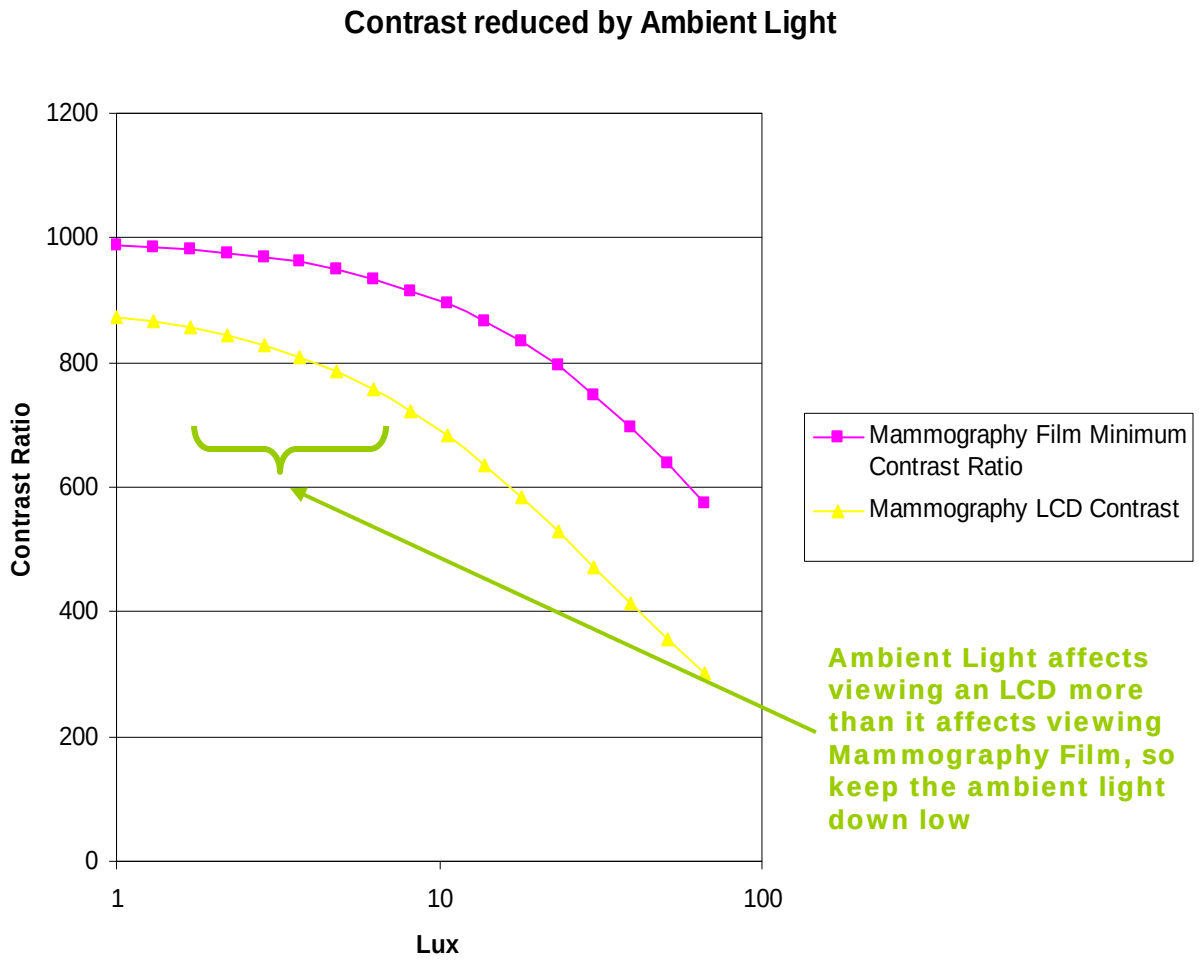


**Graph 1 – Effect of Ambient Light on Contrast**

## 6. VIEWING ANGLE

Contrast ratio of mammography film on a View box is nearly constant over a broad viewing angle. This is important because the task of reading mammograms typically requires the use of two large displays, shown in diagram 3.


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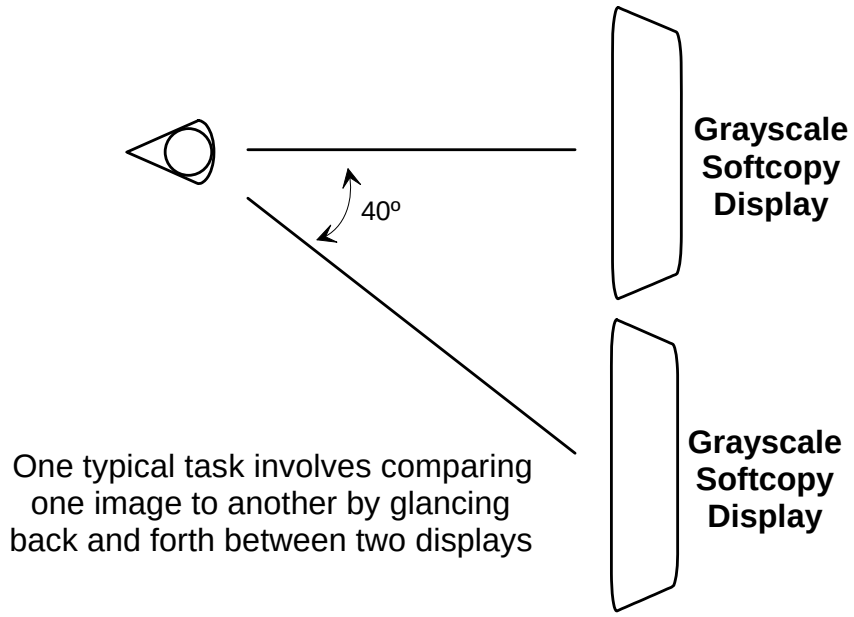


**Diagram 3 – Softcopy review using two displays**

Even when all the images are on a single display, radiologists often inspect the image quite closely, as shown in Diagram 4.

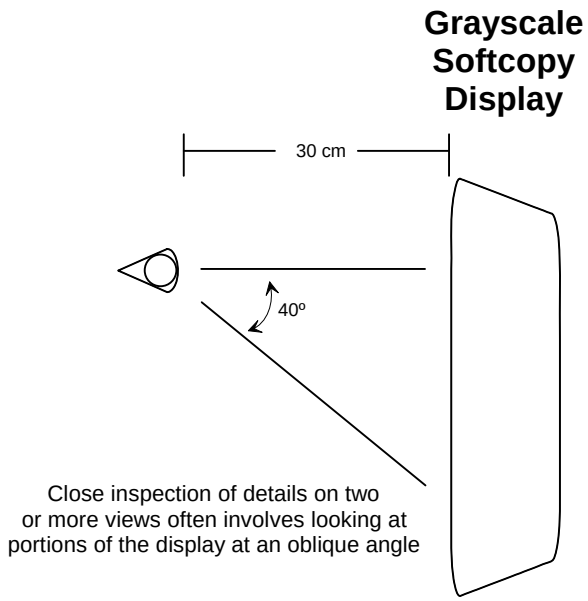


**Diagram 4 – Comparing images within one of two displays**


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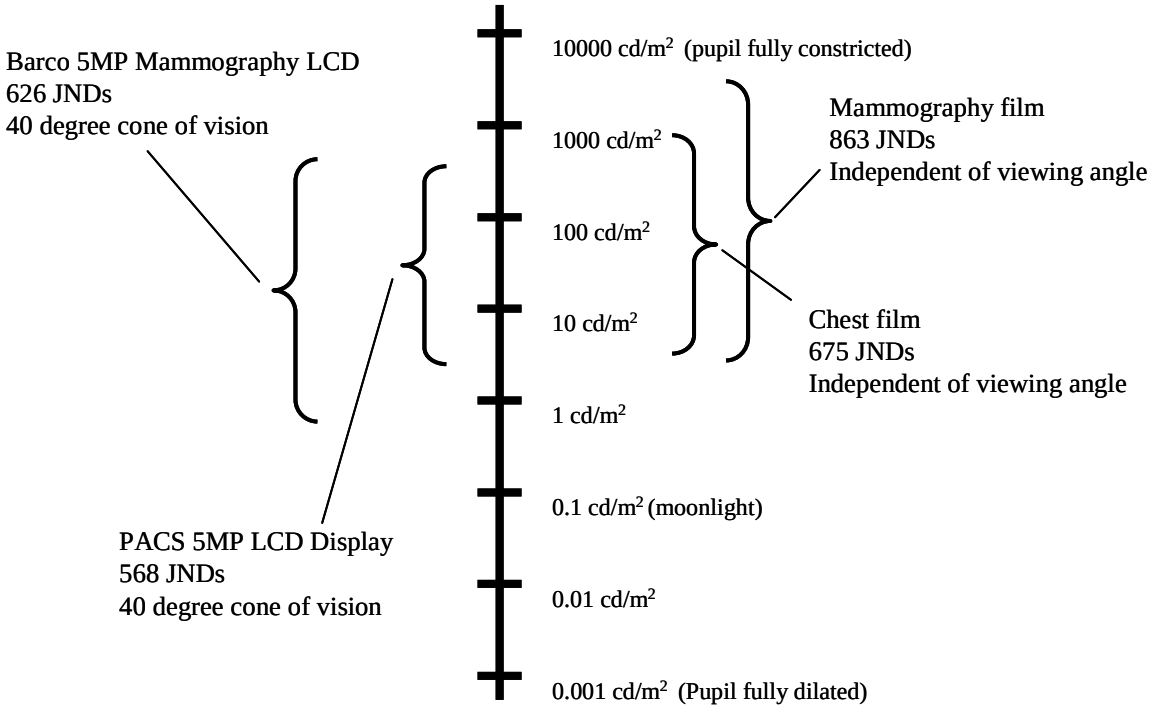
# Comparing Contrast of X-Ray Film to LCD displays

(Contrast measured in Just Noticeable Differences (JNDs)




Numerous standards cover the use of computer displays when performing activities that require a broad viewing angle. One such standard is ISO 13406-2. This defines a Class I display as providing a viewing angle that is a cone (+/- 40 degrees horizontal, +/- 40 degrees vertical).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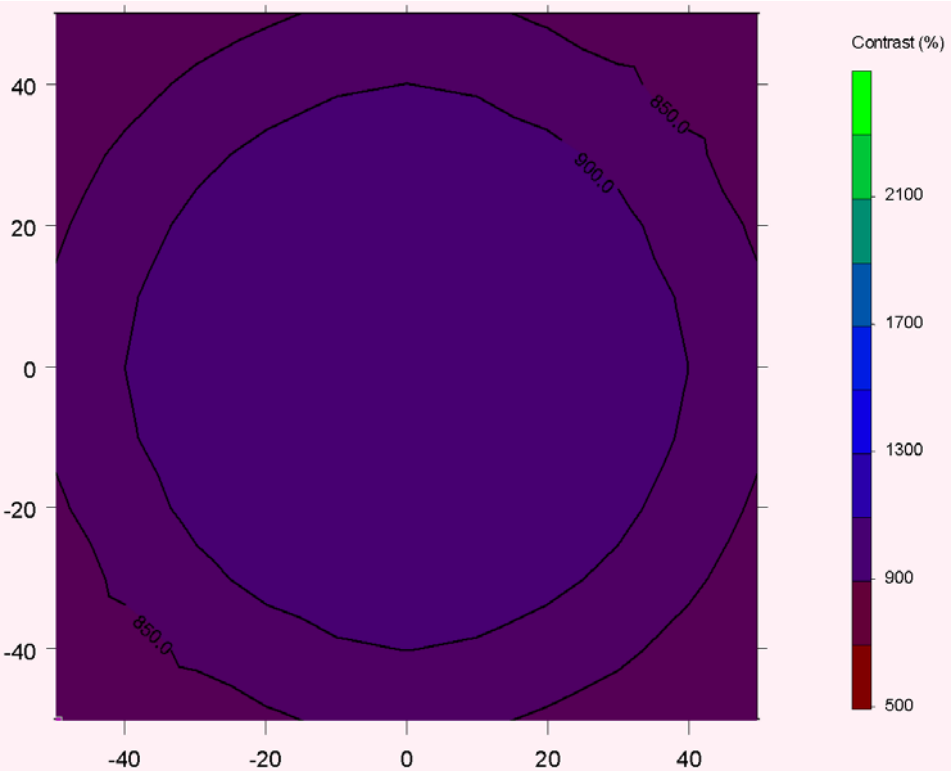


**Graph 2 – Mammography film on View box**
**Contrast versus viewing angle with 10-lux ambient light**

Two things can easily be seen on Graph 2: The view box – film combination has a contrast of about 900:1, and the contrast is relatively independent of viewing angle. This is the standard that radiologists have come to expect, and it enables fast screening of exams. How do softcopy displays measure up? It should not be surprising that the characteristics of softcopy displays are different from the characteristics of film on a view box.

The perfect reading room for digital mammography should have displays that offer excellent contrast over a wide viewing angle. A display system that offers excellent performance for mammography screening is the Coronis 5MP Mammo, available from Barco. The Coronis 5MP Mammo includes all the following components:

- Two MDMG-5121 displays - An LCD specifically designed for mammography. These include Per Pixel Uniformity, a high contrast and dark black over a wide viewing angle and a lifetime of 50000 hours with a luminance of 600cd/m2 over the entire life of the tube.


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- One Barco display controller – the latest in high definition grayscale imaging. These offer extremely fast image download of large mammography images 1000 simultaneous shades of gray, and acceleration of critical functions like Window/Level, Cine, and instant flip between hangings.
- MediCal QAWeb – a software package for softcopy QA
- Medical-instrument quality video cables capable of perfectly transmitting the high speed pixels

## 7. QUALITY ASSURANCE

The two most important aspects of any quality control system are

1) A well defined procedure
2) A responsible person with sufficient interest and authority.

All health care facilities that offer mammography screening have a QC procedure for the exposure and developing of mammography film. It is possible to extend the same basic principles that are used on film to softcopy display systems, but rather than adding this extra workload, computers actually offer a better way.
Softcopy QA has been developed along with softcopy display systems. One such QA product is the combination of MediCal QAWeb Agent and MediCal QAWeb Server, both available from Barco. Medical QAWeb Agent, installed on each softcopy Workstation, allows automatic QA tasks to be scheduled and records all the results in easy to read tables and graphs. MediCal QAWeb Server, allows secure web-based control and monitoring of the QA of all the softcopy workstations in the entire facility. With the combination of MediCal QAWeb Agent and MediCal QAWeb Server, it is possible for a facility to add softcopy QA to the existing workload of their QC technician.


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## 8. MAMMOGRAPHY READING ROOM CHECKLIST

- ☐ Room layout with good traffic flow
- ☐ Viewing equipment laid out in a line
- ☐ Displays with high contrast over 40º-radius cone
- ☐ Ambient light below 10 lux
- ☐ Adjustable vicinity lighting
- ☐ Ergonomic chairs and table height
- ☐ Noise below 45 dB
- ☐ Adequate airflow
- ☐ Utility lighting
- ☐ Thermostat & temperature control
- ☐ Quality control procedure
- ☐ Quality assurance responsible

## 9. OTHER SOURCES OF INFORMATION

*Cornell Digital Reading Room Ergonomics Checklist*
http://ergo.human.cornell.edu/AHProjects/Hronn06/CDREC.pdf

*Rethinking the Radiologist's "Office",* Gerald R. Kolb, JD
http://www.anthro.com/images/ergonomics/CarlTable_byGeraldKolb.pdf

*PRACTICE GUIDELINE FOR DETERMINANTS OF IMAGE QUALITY IN DIGITAL MAMMOGRAPHY*, American College of Radiology, oct 2007

*Computer-aided Design and Modeling of Workstations and Radiology Reading Rooms for the New Millennium*, Ratib et al., November 2000 *RadioGraphics,* 20, 1807-1816.


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