

White Paper

Characteristics of CRT and LCD displays

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Selecting the proper display for a medical application is not an easy job. This is due to the fact that no international medical guidelines exist to properly select the display that will suit your medical application.

However there exist a number of recommendations that define the minimum specification a medical display should fulfill to guide the medical professional through the process of selecting the proper display for his application requirements.

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1 CRT OR LCD

The very first question a medical professional is confronted with is whether to use CRT or LCD displays.

Deciding whether to choose for LCD or CRT is a difficult question as there are many criteria involved. Depending on the importance of each of them to the application, the final decision will favor either the LCD or CRT.

The following criteria need to be considered when selecting the proper technology.

- Image Quality
- Availability of Medical Calibration Tools
- Availability of Medical QA tools
- Total Cost of Ownership
- Space considerations
- Available budget
- Presence of legacy systems

1.1 Image Quality

Presenting a good quality image to the radiologist will reduce the need for window/level adjustments and results in improved workflow.

Medical displays offer substantially better image quality than COTS display solutions.

Which technology offers the best image quality is a complex question. Both LCD and CRT technologies have their advantages and disadvantages.

The table below summarizes the most important differences between the two technologies.

LCD	CRT
Perfect Geometry	Geometric Corrections needed
Pixelization due to black lines between pixels	Continuous image
Perfect Modulation Transfer Function (MTF =1)	Imperfect Modulation Transfer Function (MTF <1)
Uniform sharpness	Less Uniform Sharpness, even with WAVE correction
600:1 contrast ratio (Dark Reading Room)	3000:1 Contrast Ratio (Dark Reading Room)
Contrast Ratio dependent on viewing angle	Contrast Ratio independent from viewing angle
LCDs like white	CRTs like black
Imperfect Black	Perfect Black is possible
Low reflection of Ambient light	High reflection of ambient light
Poor Stability (Good with I-Guard)	Good Stability
Poor Response Speed	Instantaneous response speed
Image Retention	No Image Retention
Backlight Aging	Phosphor aging
Aging independent of image content	Aging is image content dependent
New Technology	Mature Technology
Low Power Consumption	High Power consumption
No Image Flicker	Image Flicker Present

Until recently, LCD technology was unacceptable for medical applications. But the technology has improved a lot during the past 2 years.

A recent study at a VA hospital in the US indicated that for detection of certain lesions in chest images the, 3 megapixel LCD panel showed similar results as 5MP CRT. However the study showed that more research is needed to verify if the conclusions can be generalized.

1.2 Total Cost of Ownership

As the initial investment in medical flat panel technology is still higher than CRT, one has to look at other factors to verify whether the cost remains in favor for the CRT.

An obvious factor is the power consumption of LCDs, which is about half that of an equivalent CRT display. Over the lifetime of the display this will result in energy savings, lower air-conditioning costs etc.

There is a general consensus that LCD technology is less critical to failures than the high end CRT technology. The main reasons for this are:

- Lower voltage used
- Lower power consumption

These will result in lower maintenance cost for the displays.

LCD backlights can be replaced when the lamps are exhausted. The cost for this is lower than the replacement of a CRT picture tube.

1.3 Space considerations

It is clear that if space is an issue (which is often the case), LCD technology offers a clear advantage over the bulky CRT technology.

This factor is very important as all hospitals are confronted with space limitations.

1.4 Budget

At this moment LCD technology still comes at a premium price compared to CRT. The initial investment will be higher than using CRT technology. However, one can reduce the investment considerably by choosing the right display for the right application. The lower resolution models are substantially less expensive than the high-end models.

As the technology matures, further price reductions will make LCD technology even more competitive. As premium prices are lower in the 2 Megapixel range, LCD technology will quickly replace the CRT technology.

2 DISPLAY PARAMETERS

We can characterize the displays that are available on the market in a number of categories. Separate categories can be distinguished based on resolution, brightness, uniformity, color, and calibration possibilities.

While looking at the guidelines of international organizations, it will be possible to recommend the use of certain categories of displays for certain medical applications. These will be outlined for each parameter underneath.

2.1 Resolution

There are only a few guidelines (such as The Guideline from the Korean PACS Association, German Radiology Monitor consensus) available to decide what spatial resolution is required for a particular medical application. Although these guidelines can sometimes slightly differ, they give a good indication about the minimum required resolution for different medical applications.

The table below illustrates a consensus between radiologists in Germany with regard to absolute minimal resolution requirements, image orientation and number of displays in a viewing configuration. These data were presented during the "Konsensuskonferenz für Monitorbefundung Expertenrunde".

	Color/Grayscale	Portrait/Landscape	Minimum Resolution	Number of displays per Viewing station
CT/MR	Color Color	Landscape	1600x1200 CRT 1248x1024 TFT	2
Angio/DSA	Grayscale	Landscape	1600x1200 CRT 1248x1024 TFT	2
DFR	Grayscale	Landscape	1600x1200 CRT 1248x1024 TFT	1
Projection Radiology	Grayscale Grayscale	Portrait /Landscape	1600x1200 CRT w/ Zoom 2x2.5 K CRT 2048x1536 TFT	2
Thorax	Grayscale	Portrait	2x2,5 K CRT	2
Skeletal	Grayscale Grayscale	Portrait / Landscape	1600x1200 CRT w/ Zoom 2x2.5 K CRT 2048x1536 TFT	2

2.2 DICOM GSDF support

The DICOM Gray Scale Display Function (GSDF) has been recommended for displays used in radiology. A frequently asked question is whether the display function has an impact on reading performance. A number of clinical studies^{5, 11} have demonstrated that it indeed does so.

With a non-linearized display, the observers took longer to reach a decision and ended up being mistaken more often. It is therefore strongly recommended that the DICOM GSDF function can be calibrated on a medical display system and be checked on a regular basis.

Once the display function is calibrated, it is also important that the user has no means of changing it. Displays should have the possibility to lock the brightness and contrast settings since such change will substantially alter the overall viewing function.

2.3 Brightness

The brightness level at which the display should be set is another source of confusion. According to DICOM, the number of JND's (Just Noticeable Differences) increases as the luminance increases. A 300 Cd/m² CRT display will have 630 JND's available when used in a dark reading room. A display operating at 500 Cd/m² will have over 700 JND's available. Although the luminance nearly doubles, we only see a slight increase in available JND's (+- 10 %). Whether this slight increase has a substantial influence on the final diagnosis is unknown. In either way, LCD based grayscale displays do have an advantage over CRT since they can be driven at a higher luminance. Note however that color LCD's still have a lower luminance than CRT displays. Therefore one cannot generalize that an LCD always has a superior grayscale performance. In point 3.4 we'll focus somewhat more on the color displays.

There are some clinical studies that suggest that the luminance at which the display operates does not significantly influence the final diagnostic conclusion made on the display.⁵ The same studies also show that the luminance setting of the display has a significant influence on the time to reach a final diagnosis, hence speed performance is influenced by the luminance setting.

Since a relative small amount of clinical studies are available, one should use these conclusions with caution, as the environmental conditions of a particular setup can largely influence the obtained results.

For instance, the available contrast on a display is largely influenced by the ambient light conditions. Conclusions made for a certain environment may prove to be invalid under different viewing conditions.

To address this issue, several guidelines have been issued with the DIN 6868-57 (now mandatory in German hospitals). In the US, TG 18 of the AAPM has a final guideline ready.

The German standard requires for diagnostic quality a contrast ratio of at least 100. The AAPM requires 250. For clinical review, AAPM recommends to have a contrast ratio of 100.

Contrast is defined by the ratio of the white luminance/ black luminance so it is easy to verify that even under low luminance viewing conditions, it is hard to set these luminance levels properly. Medical CRT displays usually have high quality antireflective coatings with low reflection coefficients. For these coatings the amount of diffuse reflection can be kept low. However according to AAPM even such displays should be used in diagnostic reading rooms with a luminance lower than 10 lux.

One point that is very important with respect to these guidelines is that for CRT displays the contrast ratio over a wide viewing angle will remain constant.

For LCD's however (even those specified with viewing angles of 170 degrees) the contrast ratio changes rapidly from it's maximum to about 10:1 for viewing angles of 85 degrees. This means that to be compliant with the above-mentioned guidelines, one should always look perpendicular to the medical images. In particular for multi-head systems this poses an additional burden on the radiologist.

Eye fatigue is another factor to consider. Setting the brightness too low or too high can result in excessive eye fatigue. Proper brightness setting is therefore extremely important to prevent eye fatigue.

Finally, when medical displays are operated at high luminance (CRT or LCD based displays) it should be pointed out that such settings will have a dramatic influence on the CRT or LCD backlight lifetime.

2.4. Color

For certain medical applications there is an increase in the use of color. One study made by Li and Burgess indicates that the performance of a Grayscale display was superior to a color display. Performance was 25%–30% better on the grayscale displays.

Even in those applications where the use of a color display is required this suggests that the medical color workstations should behave as close as possible to a grayscale display. Most color displays have a very poor grayscale response, which should be avoided. Color displays with a good grayscale response, calibrated to the DICOM GSDF are preferred.

2.5. Noise

Some clinical studies indicate that image noise cannot be neglected for reading certain medical images. Although a phosphor of P104 has a substantially higher brightness than a P45, its high spatial noise pattern (phosphor noise) makes it less suitable for Pulmonary Nodule Detection than a P45 phosphor. This study ⁶ indicates that the magnitude of spatial noise definitely affects the image quality.

In a comparison between CRT and LCD technology, it has been shown that LCD displays show a different noise pattern than CRT based displays. ⁷

What the clinical implications are has not been determined.

3. CONCLUSIONS

- Taking into account the different guidelines and recommendations, one could conclude that for diagnostic reading an average luminance setting between 300 and 500 Cd/m² is recommended for use in a properly darkened diagnostic reading room.
- The use of the DICOM grayscale display function is strongly recommended.
- The choice between CRT and LCD technology depends heavily on the application. LCD technology has matured to a point where it can be used for some medical applications. There is definitely a need for more basic research, but studies done so far are very encouraging for the LCD displays.

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