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The goal of the *ACR Technical Standard for Electronic Practice of Medical Imaging* is to facilitate a standard for the evaluation of digital diagnostic systems. In the preamble to the ACR Standard, the authors state:

The ultimate judgment regarding the propriety of any specific procedure or course of action must be made by the physician or medical physicist in light of all the circumstances presented. Thus, an approach that differs from the standards, standing alone, does not necessarily imply that the approach was below the standard of care. To the contrary, a conscientious practitioner may responsibly adopt a course of action different from that set forth in the standards when, in the reasonable judgment of the practitioner, such course of action is indicated by the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of the standards. However, a practitioner who employs an approach substantially different from these standards is advised to document in the patient record information sufficient to explain the approach taken.

The ACR is setting clear, measurable parameters to aid in diagnostic system assessment. Our focus will be the display system and its assessment (Section IV-D), but it is important to remember that the ACR was seeking to address the entire diagnostic imaging chain, from acquisition and storage to display and diagnosis. Ultimately, it is the practitioners of diagnostic radiology who have, by their collective actions, set the standard of care.

## Resolution and Visualization

As diagnostic radiology moved from film to computer screens, the ACR sought to set standards to assure that clinically valuable information be clearly represented on the new viewing technology. The visualization of images cannot be compromised. Acquisition, storage, and display are all key components in that imaging chain.

Section IV-D part 1 deals with the general characteristics of a display and image-viewing software. The standard was written when CRT displays were still in common use, so in setting minimum standards for contrast and brightness, the ACR was mindful of CRT limitations. Hence the minimum brightness standard was 170 cd/m<sup>2</sup>. Current LCD-based displays offer significantly more brightness than their CRT predecessors. Other base characteristics are also easily achieved, though it is worth noting that several of them pertain to the PACS software, and are not truly characteristics of the display hardware.

Section IV-D part 2 deals with low-resolution images, while part 3 addresses high-resolution images. Here we need to carefully define resolution. In acquisition, resolution means the resolving power of your acquisition system. For the ACR, the acquisition of large-matrix images (anything previously acquired on film) must be imaged to 2.5 lp/mm resolution in the original detector plate (see Section IV-A). In the display, resolution refers to the size of the pixel matrix. Thus, 3MP resolution refers to the three million pixels typically in a 1536 x 2048 pixel matrix. The two uses of the term resolution are different and are easily confused. Some display vendors have tried to exploit this confusion to suggest that one 3MP display has better resolution than another, which is false. The ACR guidelines recognize the difference, which we will attempt to clarify it here.

2.5 lp/mm was adopted as a reasonable threshold for image acquisition. This implies acquisition resolution of 5 pixels per mm to support 2.5 line-pair detection (one line on – one line off). Each pixel is at most 200 microns, which yields at least 127 pixels per inch (5 pixels/mm \* 25.4 mm/inch). For 14" x 17" film, the acquisition matrix would therefore be at least 1778 x 2159 pixels. When it comes to the display, ACR recommends higher resolution displays for chest film because a 1778 x 2159 pixel image cannot be displayed natively on a 1536 x 2048 3MP display. Note that 8" x 10" film is considered appropriate because its 1016 x 1270 acquisition matrix fits easily on a 1536 x 2048 display. The pixel density of the display has not changed. There is no 2.5 lp/mm requirement for displays. (Refer to the discussion on pg 4 of the ACR guidelines for additional information about the pixel matrix.)

Most DR and CR images are scanned at a higher resolution than 2.5 lp/mm, so an actual image matrix is often significantly larger than 1778 x 2159. Many systems acquire more than twice as many pixels. In those cases, even a 5MP display is insufficient to show the acquired image in native resolution. PACS workstations rescale the image to fit the display resolution. This rescale is necessary to show the full image on any display, regardless of the resolution.

The FDA adopted the 2.5 lp/mm standard for mammography because of the high volume of reads and the small objects that are being visualized. The FDA allows radiologists to determine suitable resolution for other tasks. All Dome E-series and S-series displays are 510(k) approved by the FDA for diagnostics. For more than a decade, the clear standard of care in the United States has been 3MP displays for general radiology; 5MP for mammography (and pediatrics in some institutions); and 2MP for clinical review. If this were not deemed appropriate by the FDA or the ACR, the FDA would have stepped in to adjust the standards for 510(k) certification.

## Display Characteristics

The ACR is recommending higher resolution displays for 14" x 17" films because of the acquisition resolution at 2.5 lp/mm, not a display resolution of 2.5 lp/mm. The pixels on the Dome 3MP grayscale displays are 206 microns and 211 microns on color displays. The difference arises because the 3MP gray LCD at 20.8" diagonal is slightly smaller than the 3MP color LCD at 21.3". If you continue this logic, shrinking the display to 20.2" would make the pixels smaller than 200 micron, but surely this does not make the display more appropriate for chest film viewing. This is because the pixel matrix of the display has not changed.

If you believe that the display needs to show the full 1778 x 2159 image matrix, as some do, you must standardize on 5MP displays to get a 2048 x 2560 display matrix. A 6MP display appears to offer high enough resolution to show the full image matrix, *but it does not*. The 6MP display has only 2048 lines, just as the 3MP displays, so the 1778 x 2159 image will not fit on the 6MP, just as it will not fit on the 3MP. The 6MP is simply two 3MP displays fused together, and it should be thought of as such. Making the pixels smaller does not provide any additional information, and it would be a gross misrepresentation to suggest that smaller pixels are inherently better for diagnostic viewing. Note again, it is not the pixel size of the display that matters, but the size of the image matrix it can present.

## Viewing Characteristics

Clearly, smaller pixel size doesn't improve diagnostic image quality alone. Only when smaller pixels are combined into a significantly larger pixel matrix can diagnostics be improved. A 5MP display has 66% more pixels than a 3MP display, but the display size is roughly the same. As a result, the pixels are smaller. What improves the image quality, however, is the number of additional pixels, not their size, which allows for the viewing of more image information. Again, the ACR is absolutely clear on this. If the display pixels had to be less than 200 microns, 3MP displays would not be appropriate for any image viewing. Yet the ACR clearly recommends 3MP displays when the acquisition image matrix can be fully shown.

The ACR recommends against reducing the acquired image matrix for display. However, as mentioned above, this already happens with all PACS workstations, because the acquisition resolution for many modalities is so much higher than the display resolution, and it continues to climb. It is not uncommon to see DR or CR systems acquiring images at 10 – 12 MP. These images all need to be reduced for viewing on a 3MP or a 5MP display. The difference in the necessary reduction to a 1778 x 2159 matrix versus a 1536 x 2048 matrix is small, which is why most US



hospitals use 3MP displays for general radiology, including chest film reads. The data loss is seen as not clinically significant.

Another area where the ACR states an unambiguous opinion is a few paragraphs after the discussion of resolution and display size. Section IV-D, part 5, item a.iii states “Protective shields on LCDs add to reflections and should not be used if possible.” This references the ACR’s clear concern about reflected light, particularly specular reflections that come off flat glass surfaces. If the ACR guidelines are the absolute standard by which displays are selected, then one must reject any display which uses a reflective glass shield. The only option in the market would be a 5MP display without a reflective shield.

The ACR is primarily concerned with the reflections that come from light sources in front of the display. However, the 6MP display has a particularly concerning reflective shield, because it is offset from the LCD by roughly 6 mm. That air gap causes internal reflections. Light from the LCD hits the back of the reflective glass and shines back onto the LCD. This can result in a slight blurring of the image, particularly in high-contrast areas.

## Reliable Solutions

Strict conformance with the ACR guidelines requires 5MP displays without reflective glass for 14” x 17” film viewing. There is no other product available on the market that meets all of the ACR requirements. However, we believe that this is an extreme reading of the ACR recommendations. Recall that the *ACR Technical Standards* explicitly indicate that “a conscientious practitioner may responsibly adopt a course of action different from that set forth in the standards.”

In the United States, the standard of care in radiology has clearly centered on 3MP displays. Outside of mammography, 3MP displays are used much more frequently than 5MP displays. This is, in part, because 3MP displays are available in color as well as grayscale. Color displays offer additional diagnostic advantages for many modalities. The addition of color is deemed by many as a valuable diagnostic tradeoff versus the slightly smaller pixel matrix than the ACR recommends.

Our objective is to give you information to help in display selection. The Dome E5 display fully meets the ACR requirements. The Dome E3, Dome E3cHB, and Dome S3c are all FDA approved for diagnostics and offer excellent options to a 6MP display, with significant viewing, installation, and maintenance advantages, and a much lower total cost of ownership. Ultimately, it is the practitioners that must make the decisions about the appropriate diagnostic display solution.