Quality-Control Issues on High-Resolution Diagnostic Monitors

Laurence F. Parr, Amanda L. Anderson, Brendan K. Glennon, and Pamela Fetherston

Previous literature indicates a need for more data collection in the area of quality control of high-resolution diagnostic monitors. Throughout acceptance testing, which began in June 2000, stability of monitor calibration was analyzed. Although image quality on all monitors was found to be acceptable upon initial acceptance testing using VeriLUM software by Image Smiths, Inc (Germantown, MD), it was determined to be unacceptable during the clinical phase of acceptance testing. High-resolution monitors were evaluated for quality assurance on a weekly basis from installation through acceptance testing and beyond. During clinical utilization determination (CUD), monitor calibration was identified as a problem and the manufacturer returned and recalibrated all workstations. From that time through final acceptance testing, high-resolution monitor calibration and monitor failure rate remained a problem. The monitor vendor then returned to the site to address these areas. Monitor defocus was still noticeable and calibration checks were increased to three times per week. White and black level drift on medium-resolution monitors had been attributed to raster size settings. Measurements of white and black level at several different size settings were taken to determine the effect of size on white and black level settings. Black level remained steady with size change. White level appeared to increase by 2.0 cd/m² for every 0.1 inches decrease in horizontal raster size. This was determined not to be the cause of the observed brightness drift. Frequency of calibration/testing is an issue in a clinical environment. The increased frequency required at our site cannot be sustained. The medical physics division cannot provide dedicated personnel to conduct the quality-assurance testing on all monitors at this interval due to other physics commitments throughout the hospital. Monitor access is also an issue due to radiologists' need to read images. Some workstations are in use 7 AM to 11 PM daily. An appropriate monitor calibration frequency must be established during acceptance testing to ensure unacceptable drift is not masked by excessive calibration frequency. Standards for acceptable black level

and white level drift also need to be determined. The monitor vendor and hospital staff agree that currently, very small printed text is an acceptable method of determining monitor blur, however, a better method of determining monitor blur is being pursued. Although monitors may show acceptable quality during initial acceptance testing, they need to show sustained quality during the clinical acceptance-testing phase. Defocus, black level, and white level are image quality concerns, which need to be evaluated during the clinical phase of acceptance testing. Image quality deficiencies can have a negative impact on patient care and raise serious medical-legal concerns. The attention to quality control required of the hospital staff needs to be realistic and not have a significant impact on radiology workflow.

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THE PHYSICS COMMUNITY must address high-resolution diagnostic monitor image quality testing. At the start of acceptance testing, we were unable to find significant information on high-resolution monitor quality-control standards from other clinical sites conducting acceptance testing. One article published in an earlier journal suggested many of the same problems with image quality as we observed.¹

During acceptance testing, we developed a program to track the performance of monitors with emphasis on high-resolution monitors. Though very time-consuming for the physics staff, the program uncovered significant monitor problems that otherwise might have gone undetected during acceptance and later clinical use.

The purpose of this report is to communicate monitor quality issues learned and estimate the time commitment physics staffs should plan for before monitors are installed.

MATERIALS AND METHODS

Initial quality-assurance testing on 10 four-monitor and 3 two-monitor high-resolution (2,000 × 2,500 pixels) diagnostic workstations and nine quality-control workstations with a single medium resolution (1,200 × 1,600 pixels) was performed on a weekly basis using VeriLUM software by Image Smiths, Inc (Germantown, MD). Quality-assurance testing was conducted monthly on 43 dual-monitor, medium-resolution (1,200 × 1,600 pixels) workstations using the same software.

Drift was not initially noted until higher than expected calibration rates were observed. After the monitor vendor returned to the site and adjusted the affected monitors, quality-control tests were increased to three times a week for all

From the Naval Medical Center, Portsmouth, VA.

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Address reprint requests to Amanda L. Anderson, Radiology, 620 John Paul Jones Cir, Portsmouth, VA 23708. E-mail: alanderson@mar.med.navy.mil.

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diagnostic workstations and a control group of three medium resolution review stations. Data recorded included vertical and horizontal raster size measurements, monitor white and black levels before and after calibration, luminance uniformity across individual monitors and between monitors, and luminance response for tracking: index value, ambient light offset, white level, and black level.

Raster size was initially established by setting the VeriLUM circle to a diameter of 11.5 inches and tracked by remeasuring this circle pattern during monitor quality-control testing. Raster size was considered unchanged if vertical and horizontal diameters were within 3% of each other and their initial values. Later, at the monitor manufacturer's suggestion, raster size was set and tracked by measuring the actual screen raster, setting the vertical raster size to 15 inches and the horizontal size to either 11.25 inches (medium resolution) or 11.5 inches (high resolution). To determine the effect of raster size on luminance, white and black levels were measured on four different medium-resolution monitors while varying the size of the raster.

Luminance was measured using the light meter provided with the VeriLum software. White level tolerance was set to 250 to 260 cd/m^2 (medium resolution) and 335 to 345 cd/m^2 (high-resolution). Black level tolerance was set to 0.55 to 0.65 cd/m^2 for all monitors. Tolerance for the high-resolution monitors was reset 245 to 255 cd/m^2 for white level and 0.50 to 0.60 cd/m^2 for black level when they were replaced by a different vendor's product. Monitor luminance uniformity was determined by measuring luminance at the center and four corners. The four corner measurements were required to be within 15% of the center value. Luminance uniformity between monitors was determined by comparing the center luminance value on each monitor to the average. The tolerance was set at 5%.

After 6 weeks of continuous testing, all diagnostic workstation monitors were replaced with monitors from another vendor. Quality-assurance testing on the replacement monitors was initially conducted weekly using the same procedures. When a calibration-reset problem was identified, testing periodicity was increased to three times weekly and in some cases, daily. All quality-assurance testing was subject to monitor and technician availability.

RESULTS

Medium-Resolution Monitors

Vendor no. 1 visited the site 1 month after initial monitor acceptance testing to address image quality concerns. Following the visit, we noted that 12 monitors from dual-monitor, medium-resolution workstations showed signs of defocusing, six monitors could not be calibrated within brightness limits, and on one monitor the Society of Motion Picture and Television Engineers (SMPTE) test pattern 5% square could not be distinguished from its 0% companion patch. Three of nine monitors from the single-monitor, quality-control stations could not be calibrated within brightness limits using regular procedures.

At the beginning of the data collection period,

medium resolution review workstation monitor white levels tended to drift slightly above acceptable limits. After a 3-month period, the trend reversed and tended to drift below acceptable limits. During the test period, raster dimensions were maintained at 15 inches vertically and 11.25 inches horizontally, as specified by the vendor. Measurements at different raster sizes were taken on four separate monitors to determine the effect on luminance. The data indicated that change in raster size had no noticeable effect on black level; white level varied by approximately 1.8 cd/m^2 for every 0.1 inches change in horizontal length.

During the test period, the six control monitors selected for intensive quality-control monitoring were recalibrated a total of 34 times due to monitor drift; 59% of the calibrations were due to white level drift. All nine quality-control workstations' monitors continued to be tested on a weekly basis. In this group of workstations, five monitors could not be effectively calibrated because the brightness control knob was at maximum low, four appeared defocused in various areas, three displayed some type of geometric distortion, and one experienced an electrical fire due to arcing inside the monitor chassis.

High-Resolution Monitors

During a 6-week test period, 83% of the initial 46 diagnostic monitors delivered displayed visible defocusing. Defocusing problems were most prominent at screen edges. Eleven percent of these monitors revealed defocusing at the center of the screens. Defocusing problems have not been observed since a second vendor replaced these original monitors with new units.

Raster size was also an issue on the diagnostic workstation monitors. Initially, geometry quality-control checks were performed by measuring the vertical and horizontal diameters of the VeriLUM test circle. The monitor vendor then specified that geometry measurements should be performed by measuring raster size. Changing raster size to the vendor's specifications placed the VeriLUM circle vertical and horizontal diameters at greater than 3% difference from one another in direct conflict with the vendor's updated manual.

Due to problems with the original monitors, the picture archiving and communication system (PACS) vendor decided to replace all monitors with a second vendor's product. The physics staff

Fig 2. One high-resolution monitor displayed signal stability over a period of 5 weeks. During this time, the workstation showed the brightness drift values to be approximately 1%.

riod: once because the white level drifted high (Fig 2) and once because the black level drifted high. Two four-monitor diagnostic workstations remained stable for 4 weeks and required no recalibration. Another dual-monitor workstation and a 4-monitor workstation remained stable for 3 weeks and required recalibration only twice due to black level drifting above range. Our results suggest that the new monitors on the diagnostic workstations maintain acceptable levels of luminance drift; however, the frequency of recalibration is still considered too high. This may be due to too stringent tolerance requirements, an issue to be reviewed by the physics staff.

We noted that several four-monitor workstations had one monitor with a gray screen of a noticeably different hue from its companions. Although visible to the eye, the difference was not identifiable through the regular calibration procedures. We chose to address this issue by rearranging monitors so all monitors on a workstation appeared the same to the trained viewer.

The quality-control checks on the diagnostic workstations consisted of a visual inspection of gray levels as displayed by the SMPTE test pattern, a visual check of geometry as shown by the VeriLUM circle, and a measure of white and black levels. A complete calibration was performed if any adjustments were necessary. Basic quality-control checks were accomplished in 5 minutes. A complete calibration required 20 to 25 minutes if only light levels required adjustment. With 13 diagnostic workstations, the process became a burden that the physics staff could not maintain to its satisfaction.

Monitor calibration procedures for both high- and medium-resolutions monitors have proved to be an issue for the physics staff. The adjustment

knobs for the medium-resolution monitors are located on the back of the monitors. A person calibrating the brightness level or changing the raster size needs to hold a luminance meter flush to the center of the screen while carefully adjusting the knobs on the rear. Although the location of the adjustment knobs makes for a more difficult calibration, they are still accessible to other personnel. In our situation, some workstations are located in the center of a room, allowing individuals easy access to brightness and contrast settings. The adjustment knobs on the medium resolution monitors also seemed to cover too limited a luminance range. White and black levels frequently could not be adjusted to within the desired range because the adjustment knob would not allow for further adjustment. When this occurred, the contractor had to use a tool to reach inside the monitor from the rear to carefully adjust the levels.

The high-resolution diagnostic monitors from the second vendor have two calibration knobs located on the back of the unit in the upper right hand corner to set brightness and contrast levels. Other monitor adjustments such as geometry or bowing are performed from an internal program accessed by spinning these two knobs simultaneously. In practice, this method of calibration has proven difficult since accessing the calibration program changes the monitor brightness and contrast. These have to be reset either by adjustment or by turning the monitor off and on, causing the stored values to be loaded. Calibration usually took several attempts, significantly altering brightness and contrast levels. Interestingly, the high-resolution diagnostic monitors from the first vendor actually had a more reasonable calibration procedure. A keypad was plugged into the front of the monitor if an adjustment was required. This allowed the tech-

nician to easily view the monitor while adjusting the desired settings using the keypad. Additionally, this arrangement prevented unauthorized persons from adjusting the monitors accidentally or purposefully.

High-resolution monitor calibration was made even more troublesome due to a video card overheating problem. This was only a problem in the four monitor diagnostic workstations. The video cards in these workstations frequently popped out of their slots due to overheating. We noted that the presence of vertical streaks in the image when displaying the VeriLUM circle pattern was a reliable indicator that a video card was overheating. Typically, a video card would pop out without warning, suddenly leaving the radiologist with a black screen.

Different approaches were used to address video card heating. Cards were frequently switched out. Some were held in place using small wooden shims. A few motherboards were replaced by the PACS vendor. Diagnostic workstation monitors were shutdown overnight or when heating appeared to becoming a problem to allow for cooling. None of these solutions were effective and significantly affected workflow. The video card overheating problem has become more frequent and more severe as time passes. Video cards are now failing and require replacement.

CONCLUSIONS

During acceptance testing for monitor image quality, the physics staff should conduct weekly monitor quality-control checks on all high-resolution diagnostic workstations, medium-resolution quality-control workstations, and a sample group of medium-resolution review workstations, depending on the number of workstations deployed. Once a diagnostic workstation's high-resolution monitors display stability, quality-control checks may be relaxed to biweekly or longer. Medium-resolution workstation quality-control checks may be conducted monthly after a period of stability has been established. This PACS site has yet to observe stability on an acceptable number of monitors.

Diligent quality-control testing of workstation monitors not only identified short-term stability issues that led to the unfortunate necessity of replacing

all the diagnostic monitors, but also proved to be a valuable indicator of overall stability of the workstations. Additionally, the heat problem in the four monitor diagnostic workstations was first detected by quality-control measurements but was not recognized at first as a heat problem. During initial monitor acceptance testing, the possibility of video card overheating should be examined.

Another issue discovered during acceptance testing was that calibration software compatibility between monitor vendors is not guaranteed. On replacement of our diagnostic monitors, the original quality-control software was kept to save the cost of purchasing 77 new software packages offered by the new monitor vendor. Although the original software was compatible with the new monitors, it could not store calibration data to the E-prom inside the monitors. This problem was only discovered by the physics staff through ongoing quality control testing. This shortfall was neither documented in the monitor's operation manuals nor noted during the vendor installation visit. Physics staffs need to be aggressive in gathering such information from the vendor.

Monitor calibration on workstations with poorly located controls is a physically awkward task. Monitors that allow a control keypad or laptop computer to be plugged into the front of the monitor make calibration far more efficient while ensuring that calibration adjustments are unchanged by unauthorized individuals.

Through exhaustive acceptance testing, we have discovered key shortfalls of the PACS system monitors that need to be addressed. In order for the PACS system to be effective, its workstations must be reliable for the interpreting radiologists, and the frequency of quality control testing and calibration procedures need to be realistic.

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REFERENCE

1. Siegel EL, Reiner BI, Cadogan M: Frequency and impact of high-resolution monitor failure in a filmless imaging department. *J Digit Imaging* 3:114-118, 2000