

Image Processing: Improving Image Quality for Digital Radiography

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Abstract

This article on advanced radiography picture preparing and show is the second of two articles composed as a component of an intersociety push to build up picture quality gauges for computerized and registered radiography. The subject of the other paper is advanced radiography picture obtaining. The articles were created cooperatively by their, the American Association of Physicists in Medicine, and the Society for Imaging Informatics in Medicine. Progressively, restorative imaging and patient data are being overseen dosing computerized information amid procurement, transmission, stockpiling, show, elucidation, and meeting. The administration of information amid every one of these activities may affect the nature of patient care. These articles portray what is known to enhance picture quality for computerized and figured radiography and to make suggestions ideal obtaining, preparing, and show. The act of computerized radiography is a quickly developing innovation that will require auspicious update of any rules and norms.

Keywords: Image Quality, Medicine, Radiography, Image Processing, Display

1.Introduction

The quality of medical images is determined by several factors, beginning with the acquisition process and the characteristics of the imaging device, and extending to the methods used for image display [1,2,11]. In digital imaging systems, acquisition and display are distinct stages of the imaging chain, which enables the evaluation and optimization of image quality at both ends of this continuum [2,11]. The assessment of image quality is also closely linked to the specific clinical task being performed [1,11]. Digital radiography is applied across a broad spectrum of diagnostic examinations, including chest, musculoskeletal, and genitourinary imaging [2,11]. Although these applications vary in clinical purpose, a set of fundamental image quality parameters can be defined that remain relevant across modalities [1,2]. The present paper addresses image processing and display in digital radiography, and serves as a companion

to a related work on image acquisition. The discussion is informed by evidence and perspectives from the peer-reviewed medical imaging literature [1,11].

1.1. Equipment Specifications and Existing Standards

The specifications for equipment used in digital image data management vary according to the application and the requirements of the individual institution. Nevertheless, in all cases, such equipment must provide image quality and availability appropriate to the clinical task, whether for primary diagnostic interpretation or for secondary review [2,5,11]. Compliance with the current Digital Imaging and Communications in Medicine (DICOM) standard, developed by the American College of Radiology (ACR) and the National Electrical Manufacturers Association (NEMA)—in particular Part 14, which specifies grayscale display functions—is strongly recommended for all new equipment acquisitions [3,4]. Furthermore, periodic upgrades incorporating the evolving features of this standard should form an integral component of continuous quality control programs [3,5].

Adherence to the technical frameworks developed under the Integrating the Healthcare Enterprise (IHE) initiative, coordinated by the Radiological Society of North America (RSNA) and the Healthcare Information and Management Systems Society (HIMSS), is also strongly advised for all new acquisitions [10]. These recommendations apply primarily to displays intended for diagnostic interpretation. Secondary displays (e.g., those used by clinicians or technologists) may not be required to meet these rigorous standards, provided they are not utilized for primary diagnostic purposes [5,13]. Several authors have reviewed the factors influencing image quality in soft-copy reading of radiographic examinations [5,11,13]. A summary of minimum quality specifications is presented below.

1.2. Network Size and Display Resolution

Soft-copy displays must render images with sufficient pixel density to allow full-image review with adequate spatial detail at a typical viewing distance of approximately 30–60 cm (with corrective lenses used as appropriate for this distance) [5,13]. Ideally, the display matrix size should match the acquisition matrix as closely as possible, or provide equivalent detail through magnification functions [3,5].

A 5-megapixel (MP) monitor ($2,048 \times 2,560$ pixels), typically used in portrait orientation with a diagonal dimension of 54 cm (21 in), exceeds the ACR standard of at least 2.5 line pairs per millimeter (lp/mm) at the detector plane for a 35×43 cm (14×17 in) radiograph [3,5]. Such monitors are therefore sufficient for reviewing most computed radiography (CR) and digital

radiography (DR) images in a single view [2,5]. By contrast, monitors with lower resolutions—such as 1-MP ($1,024 \times 1,280$ pixels), 2-MP ($1,200 \times 1,600$ pixels), or 3-MP ($1,536 \times 2,048$ pixels)—do not permit full concurrent display of a 35×43 cm image at the required 2.5 lp/mm detector resolution [3,5,13]. In these cases, zoom and pan functionality is essential to ensure that the displayed image resolution is not constrained by the limitations of the monitor's pixel matrix [5]. This consideration applies to any imaging scenario in which the detector's native element size exceeds the display matrix resolution [5,13].

Table 1: Minimum Technical Specifications for Digital Radiology Displays

Parameter	Recommended Standard	Acceptable Range	Reference/Guideline
Matrix size (pixels)	≥ 5 MP (2048×2560)	3 MP acceptable for some tasks	ACR Standard, AAPM TG-18
Spatial resolution	≥ 2.5 line pairs/mm	—	ACR Standard
Luminance (max)	≥ 170 cd/m ²	170–500 cd/m ²	AAPM TG-18, IEC guidelines
Luminance (min/black)	≤ 1 cd/m ²	—	AAPM TG-18
Contrast ratio	$\geq 250:1$	Higher preferred	Medical Imaging Standards
Pixel defects	None in central region	< 3 dead pixels per display	Manufacturer QA + AAPM TG-18

2. Image Display Technology

Display device requirements for diagnostic imaging are generally classified into two broad categories based on image matrix size. The first includes modalities that produce relatively small matrices, such as computed tomography (CT), magnetic resonance imaging (MRI), ultrasound, nuclear medicine, digital fluorography, and digital angiography. The second category includes modalities with larger matrix sizes, such as digital radiography (DR), CT in high-resolution formats, digitized radiographic films, and digital mammography [2,5,11]. The present guidelines are restricted to the use of non-mammographic large-matrix digital images; specific recommendations for digital mammography can be found in the ACR Practice Guideline for Determinants of Image Quality in Digital Mammography [4,5]. These standards apply to primary diagnostic displays used for clinical interpretation. Secondary displays, such as those employed by technologists or clinicians for review purposes, are not required to conform to the same specifications, provided that they are not used for primary diagnostic interpretation [3,5,13]. Several studies have evaluated the factors that influence image quality during soft-copy reading of radiographic examinations [5,11,13]. The essential specifications are summarized below.

2.1 Bit Depth

Diagnostic display devices must render image details with sufficient luminance resolution to preserve contrast information and avoid contour artifacts. A minimum of 8-bit luminance resolution is required; however, 9-bit or higher resolution is recommended when the acquired image data exceed 8-bit depth [3,5,11]. In general, higher luminance ratios warrant correspondingly higher bit-depth display capabilities [5].

2.2 Display Calibration

All primary diagnostic displays, as well as those used for image adjustment and evaluation (e.g., technologist review monitors), must support calibration according to the Digital Imaging and Communications in Medicine (DICOM) Grayscale Standard Display Function (GSDF) [4]. The goal of the GSDF is to ensure that images transmitted in the DICOM format are displayed consistently across all compliant monitors, regardless of manufacturer or model [3,4]. Additional performance factors, such as modulation transfer function (MTF) and noise, must also be considered. At the Nyquist frequency, the modulation transfer should exceed 35% [3,5].

2.3 Glare and Reflections

Veiling glare, or the scattering of light within the display system, reduces image contrast [5,13]. For primary diagnostic displays, a glare ratio exceeding 400 is recommended [3]. Ambient reflections should also be minimized [13]. Indirect or dimmable fluorescent lighting is preferable, whereas bright clothing and laboratory coats can increase reflection artifacts [13]. The minimum luminance of a display should be at least 2.5 times greater than ambient light levels [3,5]. While cathode ray tube (CRT) monitors are often equipped with antiglare coatings, these reduce but do not eliminate the problem [3,5]. Protective shields on liquid crystal displays (LCDs) can exacerbate reflection and are generally discouraged [13].

2.4 Color Tint and Color Displays

Both monochrome and color displays exhibit a color tint, determined by the manufacturer's white-point setting [5,13]. This tint can influence user comfort and should remain uniform across the screen. Ideally, paired monitors should be obtained from the same production batch to ensure consistency [5]. Currently, most color displays provide lower luminance and contrast ratios than monochrome displays, making them less suitable for certain radiographic applications such as chest imaging, bone studies, or mammography [5,13]. Furthermore, there are no universally accepted standards for calibrating color displays when interpreting grayscale

radiographic images [4,5]. Although the DICOM GSDF can be applied, it does not fully address the challenges of color display calibration [4,5,13].

2.5 Technology-Specific Considerations

Both CRTs and LCDs are suitable for use as primary diagnostic displays [5]. Each requires approximately 30 minutes of warm-up time to achieve optimal performance [5]. Flat-panel displays (all LCDs and some CRTs) are preferable to curved-surface CRTs, as flat geometry reduces geometric distortions [5,13]. On-axis performance is comparable between CRTs and LCDs; however, LCDs may show reduced contrast with off-axis viewing, which must be considered in multi-monitor workstations [13]. When two monitors are placed side by side, they should be angled inward to reduce the effects of angular luminance variation [13]. Contrast response should not deviate from the DICOM GSDF by more than 30% within the normal viewing angle range (typically $\pm 30^\circ$) [4,5].

2.6 Secondary Displays

Displays not intended for primary interpretation are not required to meet all the specifications outlined above. However, when used by technologists to assess image quality during acquisition, these displays should approximate diagnostic performance in terms of maximum and minimum luminance, contrast ratio, and adherence to the DICOM GSDF [4,5,13]. Resolution requirements are less stringent, provided that zoom and pan functionality allows full evaluation of the inherent resolution of the acquired image [5,13].

3. Considerations

3.1 Workstation Performance

Display workstations intended for the primary interpretation of large-matrix digital images should support several essential functions. Images must be retrievable and displayed within three seconds or less [5,11]. Users should be able to select image sequences and display formats easily, with customizable hanging protocols tailored to individual preferences [5,11]. These protocols should ensure proper image labeling and orientation [10]. Navigation between prior and current studies must be rapid and intuitive, and tools for image rotation or flipping should be available, provided that patient orientation is preserved [10,13]. Patient demographic and study information must be accurately linked with the displayed images [10]. The complete set of images from each study should be accessible during interpretation. Although simultaneous display of all images is not required, dual-monitor configurations are desirable to facilitate comparative viewing [5,13].

3.2 Technical Parameters

Clinically relevant acquisition parameters—such as tube current, kilovoltage, bit depth, exposure time, and matrix size—should be readily available at the workstation [2,11]. Display of the exposure index in the picture archiving and communication system (PACS) is critical for evaluating image quality, estimating patient dose, and providing feedback to technologists [2,11].

Window and level adjustment tools must be incorporated, since the full dynamic range of medical images cannot be optimally displayed without contrast modification [5,11]. Preset window and level settings (e.g., lung and bone windows) are recommended to improve workflow efficiency [5,13].

3.3 Image Processing and Data Types

Any use of irreversible compression, image pre-processing, or cropping should be documented in the image record [4,10]. Zoom (magnification) and pan functionality should allow visualization at the original spatial resolution of the acquisition system [3,5]. Workstations should also provide tools for linear measurements and pixel value analysis (e.g., Hounsfield units in CT), calibrated against the acquisition device [5]. Proprietary image-processing algorithms are frequently applied by manufacturers to enhance image quality [6,7]. The nature and scope of these algorithms should be clearly explained to users [6,7]. A distinction should be maintained between for-processing data (raw image data prior to proprietary adjustments) and for-presentation data (images after processing) [4,11]. Once transferred to the review workstation, images may undergo further modifications such as edge enhancement, histogram equalization, or grayscale adjustments [5,11]. The impact of these tools on diagnostic accuracy versus subjective image quality remains an important area of investigation [6–9,12].

3.4 Computer-Aided Detection and Diagnostic Tools

Computer-aided detection (CAD) and diagnostic (CADE/CADx) tools are increasingly being validated for clinical use by the Food and Drug Administration across a range of modalities—for example, pulmonary nodule detection in chest radiography and CT, or polyp detection in CT colonography [9,12]. These systems have generally been shown to enhance radiologist performance, although the incremental benefit may be less pronounced for experienced subspecialists compared with general radiologists [9,12].

To ensure reliability, CAD algorithms should ideally be applied to for-processing rather than for-presentation data, as extensive image post-processing may reduce algorithm effectiveness

[6,9,12]. Radiologists employing CAD systems should be familiar with their sensitivity and specificity profiles in order to critically evaluate CAD prompts and determine their clinical relevance [9,12].

4. Digital Imaging Reading Environment

The physical design of the digital reading room has a significant impact on radiologist comfort, fatigue, and ultimately diagnostic accuracy [5,13]. Optimal viewing conditions are achieved by controlling ambient lighting to minimize reflections on the screen while maintaining sufficient light for visual adaptation [13]. Ambient light should neither be completely eliminated nor excessively bright; levels between 25 and 40 lux are generally appropriate [13]. Adjustable lighting with neutral filters and dimmer switches is recommended, whereas fluorescent lighting should be avoided [13]. Supplemental desk lighting with focused or shielded sources (e.g., for note-taking) may be used in combination with ambient lighting [13].

Where film viewboxes and soft-copy displays coexist, partitions should be installed to reduce reflections and glare [13]. If partitions are not feasible, digital displays should be positioned at right angles (90°) to viewboxes rather than directly opposite them [13]. Environmental factors such as airflow, temperature, and humidity must be optimized [13]. Depending on local conditions, direct workstation ventilation under user control may be required. Water-cooled computers may be considered, as they provide both thermal efficiency and noise reduction compared with fan-cooled systems [13]. Monitors should not be placed adjacent to lightboxes; if proximity is unavoidable, they should again be oriented at 90° rather than 180° to minimize reflections [13].

Workstations should be separated with movable partitions to facilitate both consultation and individualized noise control [13]. Acoustic considerations, such as isolating transcription systems or using sound-absorbing walls, further reduce distractions [13]. Ergonomic requirements include chairs with lumbar support and adjustable height and armrests, height-adjustable tables, and appropriately positioned input devices [13]. Keyboards, mice, and monitors must be arranged to maximize comfort and efficiency [13]. Ergonomic alternatives to standard mouse and trackball devices should be considered [13]. Workstations should also provide convenient access to transcription tools, internet resources, and reference databases [10,13].

Table 3: Recommended Reading Room Environment

Parameter	Recommended Value/Practice	Rationale
Ambient lighting	25–40 lux	Reduces glare and eye strain
Lighting type	Neutral filtered, dimmable lamps	Minimize reflections, adaptable brightness
Fluorescent lights	Avoid	Cause glare and flicker
Workstation placement	90° to view boxes or bright sources	Reduce screen reflections
Temperature/humidity	Stable, user-controllable airflow	Improves comfort and system stability
Acoustic environment	Noise-minimized, water-cooled computers	Reduce fatigue, improve focus
Ergonomics	Adjustable chairs, tables, input devices	Prevent musculoskeletal strain, increase efficiency

5. Display Performance and Quality Monitoring

All digital radiography display devices must undergo performance monitoring in accordance with manufacturer specifications, applicable industry guidelines, and relevant regulatory requirements [3–5]. In the absence of manufacturer procedures, the testing methods and frequencies outlined in the AAPM Task Group 18 report (Assessment of Display Performance for Medical Imaging Systems) should be followed [3]. Because cathode ray tube (CRT) and liquid crystal display (LCD) devices exhibit different degradation patterns, as do grayscale versus color monitors, regular monitoring is essential [5,13]. At minimum, display parameters should be evaluated monthly, with increased frequency for older devices prone to luminance drift [3,5]. Monthly visual inspection for dead pixels is also necessary, as automated quality assurance systems may not detect them [5]. Routine quality checks should include the use of test patterns (e.g., SMPTE or AAPM TG18) to verify system performance under normal operating conditions [3,5]. Specific tests include:

- Spatial resolution: confirmation of at least 2.5 lp/mm [3,5].
 - Display fidelity: SMPTE test patterns should occupy the full display area, free from artifacts such as blurring, bleeding, or aliasing [3,5].
 - Dynamic range: both 5% and 95% gray levels should be clearly distinguishable from adjacent 0% and 100% areas [3,5].
- All primary interpretation monitors should be tested at least monthly to ensure diagnostic reliability [3,5,13].

6. Image Transmission, Retrieval, and Archiving

6.1. Compression

Data compression may be applied to facilitate transmission and storage. The appropriate level depends on image type, clinical purpose, and diagnostic requirements [4,10]. Both reversible (lossless) and irreversible (lossy) techniques may be used, provided that clinical quality is not compromised [4,10]. Compression algorithms accepted by the DICOM standard, such as JPEG-2000, are recommended [4]. The type and ratio of compression for each modality should be determined and periodically reviewed by a responsible physician [4]. In some jurisdictions, regulations may also require the display of compression ratios on the image [4].

6.2. Transmission

The choice of transmission system depends on the clinical environment [10]. For diagnostic purposes, the received digital data must preserve all clinically significant information [4,10]. Transmission systems must include adequate error-checking protocols and conform to the DICOM Transmission and Storage Standards, particularly the DICOM DX Image Information Object Definition, which should ideally be used across all vendors [4,10].

6.3. Archiving and Retrieval

Digital imaging systems must provide sufficient storage capacity to comply with institutional, state, and federal requirements for medical record retention [10]. Images may be stored at either transmitting or receiving sites; if stored at both, each facility's retention requirements must be satisfied [10]. A written retention policy is mandatory. Each examination record must include accurate patient identifiers (e.g., name, ID number, accession number), examination details (date, type, and facility), and ideally a brief clinical history [10]. Prior examinations must be retrievable within a timeframe consistent with clinical needs [10]. Archival procedures should provide the same level of protection as hard-copy storage, with information exchange conducted in accordance with the Integrating the Healthcare Enterprise (IHE) initiative using current DICOM and HL7 standards [10].

6.4. Security

Digital imaging systems must adhere to privacy regulations, including the Health Insurance Portability and Accountability Act (HIPAA) and applicable state laws [10]. Systems should incorporate network and software security protocols to ensure patient confidentiality, user authentication, and data integrity [10]. Protective measures must safeguard against both

intentional and accidental data corruption [10]. For teleradiology, additional mechanisms such as virtual private networks (VPNs) may be required [10].

6.5. Reliability and Redundancy

High-quality patient care depends on the stability and reliability of digital image management systems [10]. Facilities must establish written policies and procedures to ensure continuity of operations equivalent to those for hard-copy records [10]. This includes provisions for internal redundancy, backup communication links, and disaster recovery planning [10].

7. Conclusion and Observations

Digital radiology encompasses a wide range of modalities and interpretive tasks, with images acquired at varying resolutions, bit depths, and matrix sizes [2,11]. The responsibilities of a radiologist differ depending on the clinical request, which makes the establishment of comprehensive practice guidelines both essential and challenging [1,2,11]. The guidelines presented in this document address image quality from a technical standpoint. These parameters are relatively straightforward to measure and are applicable across most digital radiology reading environments [5,11]. Importantly, multiple studies have demonstrated a strong association between these technical metrics and clinical interpretation performance [11,13].

An optimized reading environment not only enhances diagnostic accuracy but can also improve efficiency in image interpretation [5,13]. One of the pressing challenges in current practice relates to the increasing availability and affordability of consumer-grade commercial displays [5,13]. While these devices are beginning to approach the resolution and luminance of dedicated medical-grade monitors, they are typically color displays not optimized for grayscale imaging [5,13]. Such displays often have lower contrast ratios and higher noise levels, both of which may compromise image quality and diagnostic accuracy [5,13]. Further research is needed to assess their impact on radiologic interpretation [5,13].

At the same time, the growing use of color in radiologic imaging—such as color Doppler sonography and three-dimensional renderings of CT and MRI data—has expanded the appeal of color displays [5,13]. The development of advanced 3D and stereo color displays introduces new possibilities for image interpretation, potentially transforming how information is presented [5,13]. However, evidence regarding their effect on diagnostic accuracy, workflow, and efficiency remains limited, highlighting the need for future investigation [9,12,14].

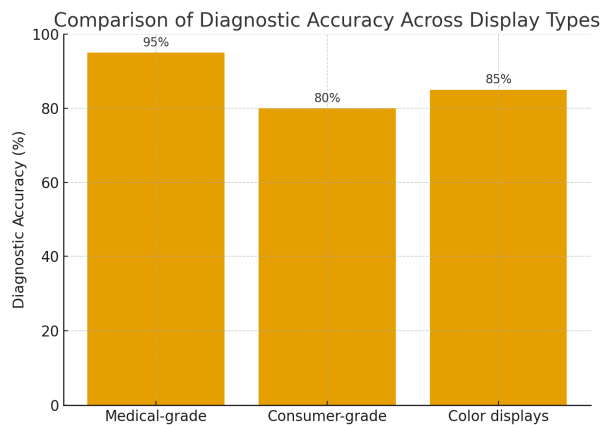


Figure 1. Comparison of diagnostic accuracy across different display types (medical-grade, consumer-grade, and color displays).

Digital radiography, like medical imaging as a whole, will continue to evolve. Display technologies will inevitably advance, yet the fundamental requirement to maintain high standards of image quality remains unchanged. The parameters outlined in this document represent a core set of minimum standards that should continue to guide clinical practice. As new display technologies emerge, they must be rigorously evaluated to ensure compliance with these principles and to safeguard the accuracy and reliability of radiologic interpretation.

Table 2: Comparison of Medical-Grade vs Consumer-Grade Displays

Feature	Medical-Grade Display	Consumer/Commercial Display	Clinical Implication
Resolution	High (≥ 5 MP, optimized for radiology)	Moderate (≤ 2–3 MP)	Lower detail, may miss subtle findings
Luminance	High, stable, calibrated	Variable, drifts over time	Reduced visibility of subtle structures
Contrast ratio	High (true black levels)	Lower (blacks appear grayish)	Loss of fine contrast
Calibration	DICOM GSDF calibration supported	No built-in calibration	Inconsistent brightness/contrast
Noise	Low electronic noise	Higher background noise	Degrades image quality
Cost	Expensive	Inexpensive	Tempting alternative but risky for diagnosis

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