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Diagnostic printing in the digital era

A white paper to help medical professionals meet diagnostic hardcopy requirements

White paper

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Introduction: the continued demand for medical hardcopy

The introduction of PACS and digital patient records has not eliminated the demand in many areas of the world for medical hardcopy, especially with the expanding footprint and range of diagnostic imaging modalities.

There are clear reasons for this continued demand for medical hardcopy:

Diagnosis: Medical hardcopy film is, in many situations, the primary medium for the doctor's diagnosis. This remains true even when records are available in digital format. Furthermore, when non-diagnostic monitors are being used, diagnostic hardcopy is required in order to diagnose the image.

Communication with other medical specialists: Not all locations have the (complex) infrastructure needed to share digital images in a secured and reliable way. In addition, doctors working in such environment, especially those who look only occasionally at images, will often feel more comfortable working with diagnostic hardcopy.

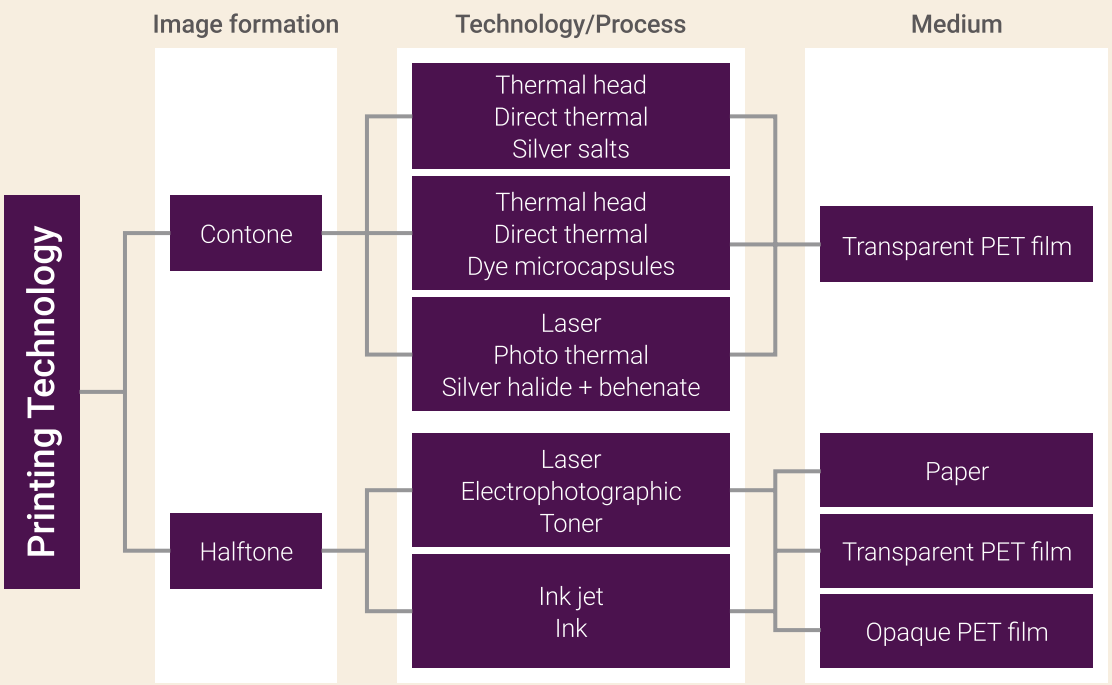
Patient: A printed diagnostic hardcopy can be an easy and reliable way to provide the diagnostic image to the patient, who can archive it, use it to request a second opinion from another doctor, etc.

But while there are many technologies for printing medical hardcopy, not every one assures diagnostic quality. Differences in the physical properties of the various print media also make some unsuitable for use in a diagnostic environment. For example, certain media are not stable: their preservation in archives and their stability over time for diagnosis cannot be assured.

Printing technologies: diagnostic quality vs referral quality

The following printing technologies are mainly used for medical imaging, whether for diagnostic images or referral images:

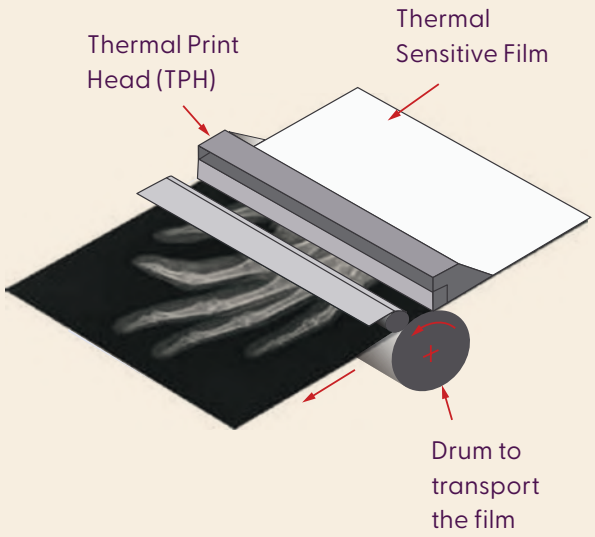
FIGURE 1
Overview of the most relevant printing technologies for medical hardcopy



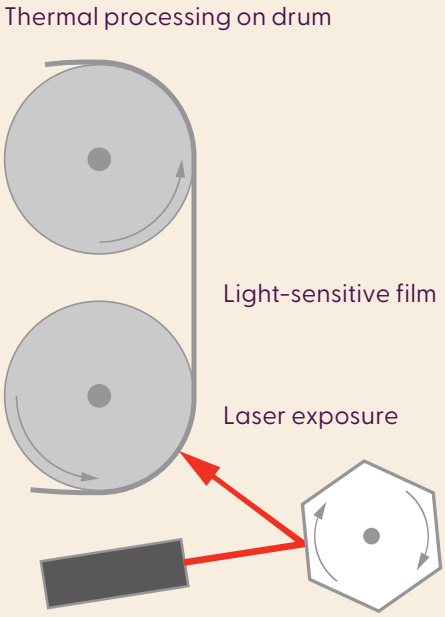
Thermography: imaging technology based on image-wise thermal modulation and development of dispersed silver salts. The process utilizes a polymeric layer containing a light-insensitive organic silver salt, a reducing agent and a stabilizer, coated on a polyester support. Reduction of the organic silver salt by the reducing agent, accelerated by heat (100 °C – 200 °C), yields a metallic silver image whose densities are controlled by the adjustable temperature of print head elements. The integrity of the silver image under normal storage conditions is secured by stabilization of the unused silver salt. This is the technology used in Agfa's DRYSTAR portfolio.

Photothermography: imaging technology based on thermal development of a light-induced latent image in dispersed silver salts. The process involves a polymeric layer containing light sensitive silver halide crystals, light insensitive silver behenate crystallites, silver soaps and a reducing agent coated on a polyester support. A latent image formed by light exposure of the silver halide crystals catalyzes an oxidation-reduction reaction between the silver behenate and the reducing agent upon heating above 120 °C. This yields a metallic silver image by physical development.

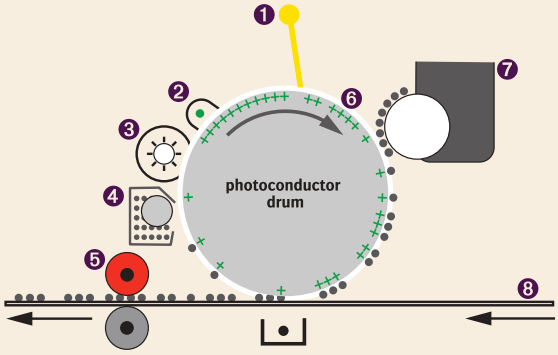
THERMOGRAPHY



PHOTOTHERMOGRAPHY

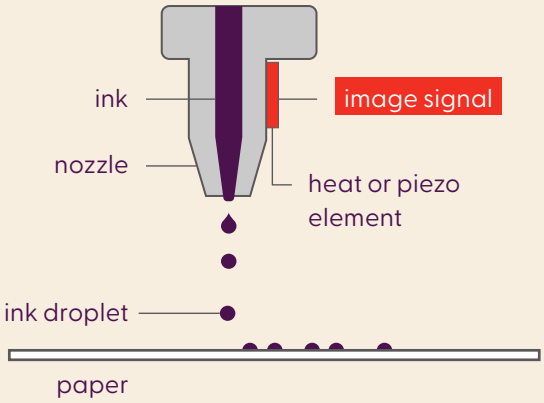


ELECTROPHOTOGRAPHIC PRINTING



1. laser
2. drum charging corona
3. residual charge removal
4. residual toner cleaner
5. fuser
6. latent image
7. developing unit with toner
8. paper

INKJET (WET JETTING/DROPLETS)



Microcapsule: imaging technology in which heat-responsive microcapsules containing dye precursors are thermally rendered to develop a dye image. The microcapsules are dispersed together with a development emulsion on a polyester support. Application of computer-modulated heat that matches the density pattern of a digital image renders the walls of the microcapsules differently permeable. The varying amounts of developer, which penetrate the capsule walls, produce corresponding differences in dye image density. The capsule walls revert to their impermeable state on cooling and provide protection against dye formation and dye degradation under normal storage conditions.

These printing technologies are mainly used for high quality and diagnostic printing on a transparent film.

Electrophotographic printing and **aqueous inkjet** are mainly used today in medical imaging for referral printing. Electrophotographic technology, found in office printers and photocopiers, uses a laser to print a latent image on a charged photoconductor drum. Toner is deposited on the drum, and transferred to paper or a polyester-based support. Aqueous inkjet imaging technology creates images through the modulated deposition of microdroplets of water-based ink on the surface of an ink absorbing layer coated on a polyester support.

Printing requirements for diagnostic images

The requirements for printing today are more diverse than ever before, due to the expanded range of modalities for diagnostic imaging. At the same time, an image that enables a correct and accurate diagnosis is key in radiology. Therefore, the most important consideration in selecting a printer for diagnostic printing is the ability **to print an image with diagnostic quality** that can be used for primary reading by a radiologist or another medical specialist.

Many parameters can determine whether a printer can print diagnostic quality images, including spatial resolution and contrast resolution.

Spatial resolution is best expressed in pixels per inch (ppi), which indicates the number of pixels used to construct/print the image. The required resolution is defined by the viewing capabilities of the human eye. The human eye (with normal or corrected-to-normal vision) can distinguish two points with a distance between them of 1/60 degrees. For the viewing distance of 30 cm typically suitable for diagnostic tasks, this corresponds to 80 µm, equaling a spatial resolution of approximately 300 ppi.

This resolution guarantees that, for most modalities, such as CT and MR, all pixels can be printed. A higher resolution would not improve perceived image quality, unless optical magnification were applied. Other applications, such as full field digital mammography, require a higher resolution (e.g. 508 ppi) to display all details.

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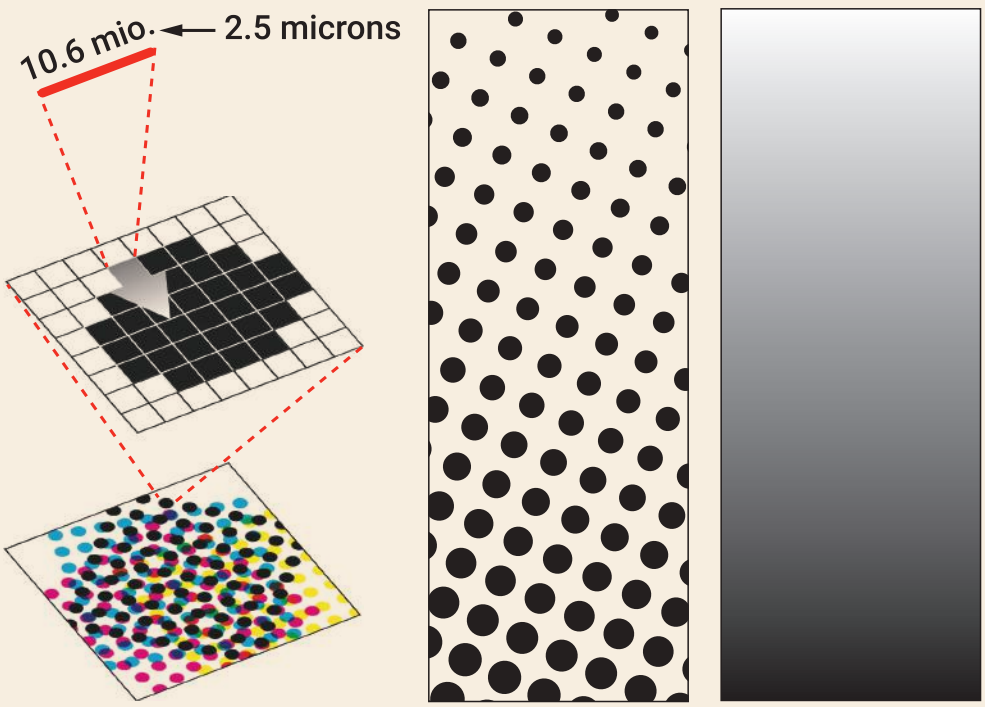
A pixel represents an image point with a certain greyscale level as image information.

- In **contone** technologies, each pixel can be rendered with quasi-continuous levels of greyscale within the density range of the printer. Examples include photo-thermal, thermal hardcopy and micro capsules.

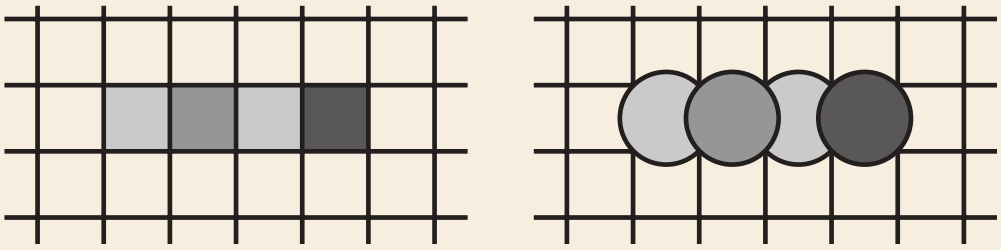
- In **halftone** printing technologies, an image point is constructed by an array of dots on the sub-pixel level. Dot sizes have to be considerably smaller than the pixel, and the addressability of dots (expressed as dots per inch (dpi)) must therefore be higher. In the most basic cases, dots can only be switched on and off. Screening algorithms, including error diffusion, are used to determine the distribution of on- or-off dots within the "dot mask" (the n x n array representing a pixel). Examples are electrophotography ("toner") and inkjet printing. In other types of halftone printing, dots can have multiple levels. Examples include inkjet printers with multiple dot-size printing capability or with black inks of different print density. **Halftone printers aim to mimic contone performance.**

FIGURE 2
Spatial resolution versus addressability



Spatial resolution must not be confused with addressability. Addressability is the number of dots that can be printed or addressed, while spatial resolution is the amount of detail that is actually printed. For contone printers, dpi and ppi can be used interchangeably. For halftone printers, however, often only the dpi information is provided. This is not sufficient to judge visual image quality, but can be compared with the dpi value of contone printers.

FIGURE 3
Spatial resolution and addressability

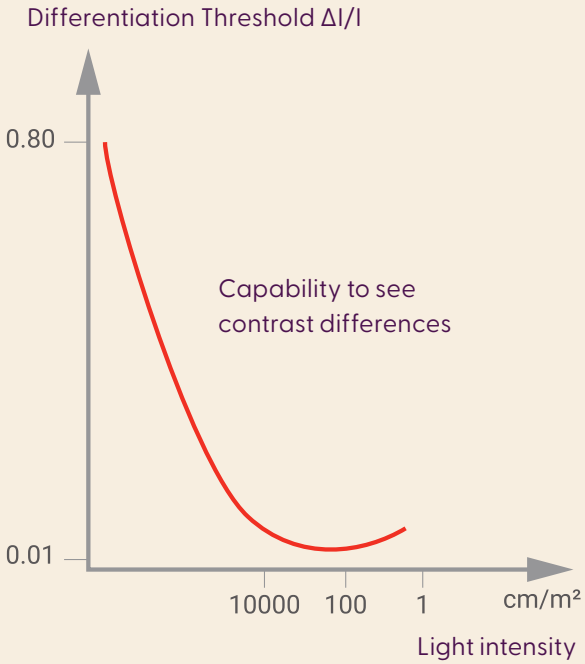


Same addressability

"Lower Spatial resolution"

- Spatial resolution ≠ addressability
- Addressability = number of dots that can be printed or addressed
- Spatial resolution = amount of detail that is actually printed
- In data sheets "resolution" is often addressability

FIGURE 4
Kanamori curve



Contrast detail resolution is another important parameter for a good diagnostic quality. Contrast detail incorporates both image contrast and resolution, in order to distinguish differences in image intensity. A high contrast detail resolution is necessary for confident diagnosis of subtle density differences in an image, for example masses in liver or brain tissue. It is measured by testing how image contrast changes as the imaged structures get smaller and closer together.

The ability of the human eye to distinguish the resolution of contrast details depends on many factors, including illumination level and size and content of the viewing field. The best differentiation between two luminance stimuli is obtained in the range of 100 – 250 cd/m² and can be as low as 0.01 of relative intensity discrimination (**ΔI/I**). The relation between the differentiation threshold and luminous density was graphed by Mr. Kanamori in the early 1960s, and is not linear.

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The visual system and DICOM

In the 1990s, Peter G.J. Barten[1] proposed a parameterized model of human vision that includes neural noise, lateral inhibition, photon noise, the optical modulation transfer function of the eye and other factors. This model of the human visual system represents a single continuous mathematical function which in its curvature falls between a log-linear response and a Display Function that may yield perceptual linearization in complex scenery with a wide luminance range.

This is the model chosen to define the **standard greyscale display function in the DICOM** protocol (Digital Information Communications in Medicine standard[2]), which provides **optimal viewing conditions for the diagnostic task**.

There are a number of practical conclusions following from these findings:

- By preference, medical images should be reproduced with the important diagnostic information in the area of approximately 100 – 250 cd/m². This can be achieved using a transparent hardcopy film system with a light box with a luminance value of 2,000 cd/m² for CT, MRI and GenRad X-ray applications, and of 4,000 cd/m² for mammography applications (European Guidelines on Quality Criteria for Diagnostic Radiographic Images – 1996). The important diagnostic information should be in the density range of 0.5 to 2.2 O.D.

- According to DICOM, JND (just noticeable difference) values offer a better representation of the greyscale perception than visual density. JND values express the perceived greyscale in terms of luminance levels L that are just distinguishable. This correlation is described by the DICOM SDF (standard display function). When a printer is calibrated (linearization) according to DICOM SDF, the contrast representation has a contrast (JND) that is (approximately) constant over the whole density range. This enables the most contrast details to be seen in the image.

An SMPTE test pattern (figure 5) can be used to achieve this calibration. Figure 6 gives the relationship between the JND contrast and the optical density for a DICOM SDF-calibrated system, which shows nearly constant number of JND levels between visual density 0.5 and 2.2 of the hardcopy film.

1 Barten, P. G. J. (1999). Contrast sensitivity of the human eye and its effects on image quality, Technische Universiteit Eindhoven DOI: 10.6100/IR523072

2 Digital Imaging and Communications in Medicine (DICOM), Part 14: Grayscale Standard Display Function, National Electrical Manufacturers Association, USA

FIGURE 5
SMPTE pattern

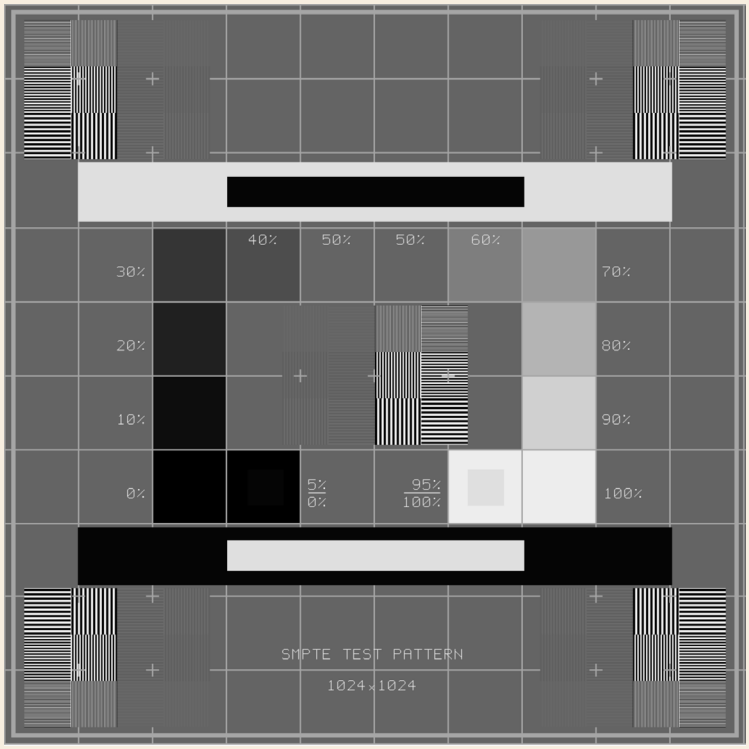
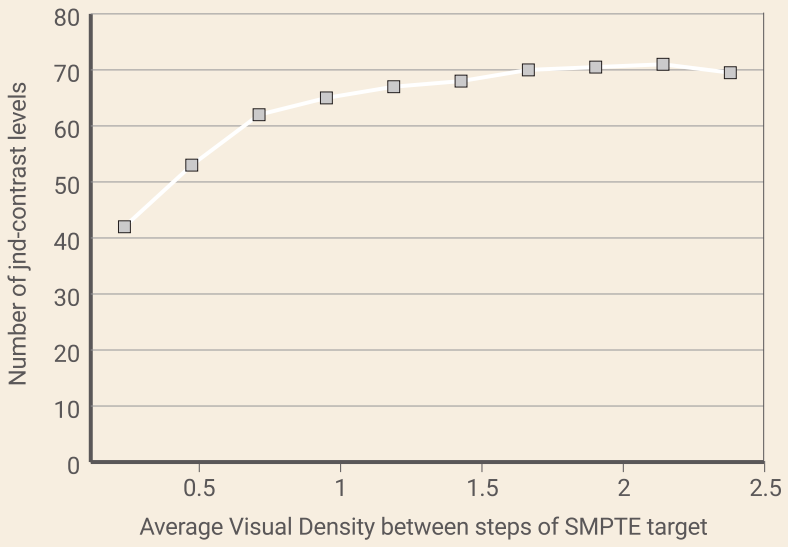


FIGURE 6
JND contrast between adjacent SMPTE steps



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The importance of DICOM protocols for hardcopy printing[3]

The DICOM standard is used for diagnostic imaging modalities to manage, store, communicate and print diagnostic images. Supporting DICOM is an important requirement for printers in a diagnostic system since it is used to communicate and print images in a controlled way, to guarantee the diagnostic quality. Non-DICOM devices (such as inkjet and paper printers not originally designed for medical imaging) may be able to accept DICOM files through conversion boxes, but the diagnostic quality of the converted printable image is not always assured. Furthermore, while diagnostic quality printers incorporate all the calibration capabilities and meet the criteria for guaranteeing diagnostic print quality, non-diagnostic printers cannot always incorporate this.

Spurious light from the environment or direct reflections off the display can 'dilute' the retrievable diagnostic information. Therefore, the DICOM protocol also defines low ambient light levels for optimum access to the diagnostic information in the image. In addition, the observer must take the time to adapt the visual system to the viewing situation. The ambient level should not exceed 1/100 of the highest luminance level of the displayed image, so as not to impair the diagnostic information. The color temperature and the spectrum of the light must also be optimal for diagnosis (Figure 7). (These general considerations are true both for emissive displays (monitors) and for hardcopy film viewed in transmission on a light box.)

However, medical images printed on opaque, reflective hardcopy materials violate this approach, because they require high ambient levels of 1000 lx or more to inspect the images. Such high levels of ambient illumination impact the adaptation of the observer's visual system. Second, the high ambient illumination results in a high level of light intensity reflecting off the print surface, dramatically decreasing the dynamic range and the discernable grey levels, especially in the dark regions of the image. In both cases, the suboptimal observer response increases the probability of an incomplete assessment of the diagnostic information in the image.

For this reason, paper or opaque media may only be used for referral applications when for example the diagnosis is done on a medical, calibrated PACS monitor.

3 "Displays Chapter 3: DICOM Basics Pertaining to Displays", Mike Flynn, PhD; Department of Radiology, Henry Ford Health System, https://siim.org/page/displays_chapter3

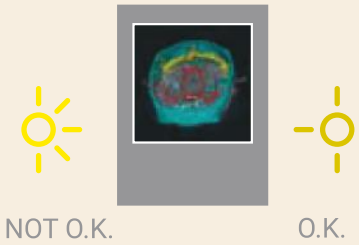
FIGURE 6
Lightbox viewing conditions

A lightbox that is too dark or too bright reduces the ability to discern small contrast differences.

- For optimum density differentiation, the lightbox intensity should be between 2000-4000 cd/m2 in order to get the important information in the density range of 0.5-2.2.

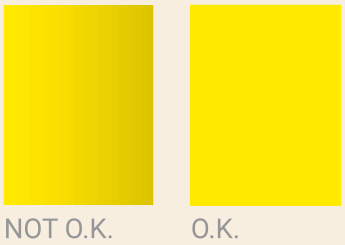
Extraneous light from non-covered areas alters the adaptation level and scatters within the reader's eye, causing dazzle that decreases contrast discrimination.

- Non-covered areas must be covered.



Excessive ambient light reduces contrast, while a dark ambient causes the pupils to dilate, resulting in deterioration of visual acuity.

- The ambient light should be moderate.



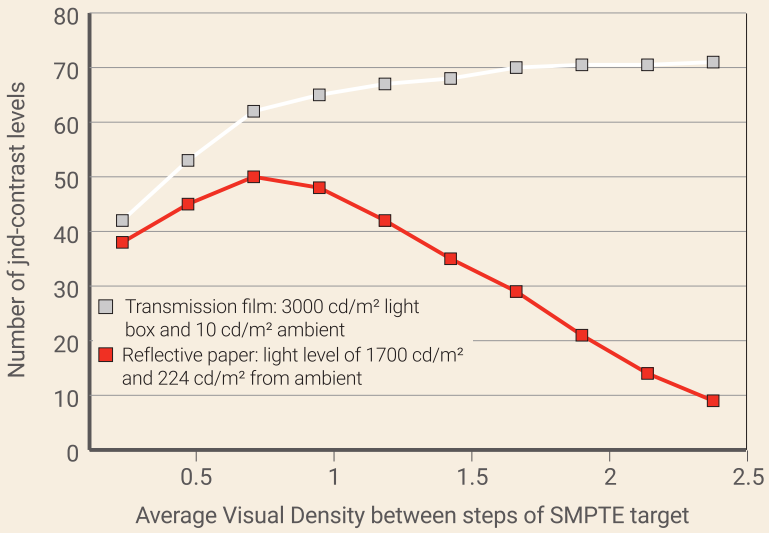
A lightbox with uneven illumination leads to wrong interpretation in the clinical image.

- The lightbox illumination should be even.

The European Commission lays out principles for image viewing conditions in its "European Guidelines on Quality Criteria for Diagnostic Radiographic Images", available on https://bookshop.europa.eu/en/home/. Other specified conditions include:

- The color of the illumination should be white or blue and should be matched throughout a complete set of film illuminators.
- It should be possible to magnify details in the displayed radiographic image by a factor of 2 to 4, with the possibility to identify small image details of sizes down to 0.1 mm.
- For viewing exceptionally dark areas in the radiographic image, an additional spotlight with iris diaphragm providing a brightness of at least 10,000 cd/m² should be available.

FIGURE 8
Benchmark of retrievable JND levels of medical images as a function of viewing mode (transmission on light box vs. reflective in ambient room), calculated according to DICOM.



Medical-certified printers: the impact on diagnostic quality

As mentioned above, some printing technologies use halftone or dithering (image processing techniques in which noise is intentionally applied in order to randomize signal processing error) to build grey levels in a pixel. However, the image structure on the sub-pixel level is substantially different from the continuous tone systems proven diagnostic printers use exclusively. The ability to resolve the sub-pixel and change the perceived structure of the pathology being inspected in the former case depends on the keenness of the individual observer, which can impact the diagnostic quality. For this reason, in certain countries printers using these technologies are not approved to print diagnostic images for CT, MRI and X-ray.

Furthermore, most medical applications require medical-certified printers that meet criteria for guaranteed safety and performance in challenging healthcare environments.

Film formats and the physical properties of the film material (such as glossiness, thickness, rounded corners, film hue, scratch resistance, etc.) also play an important role, as do the productivity (access time, throughput, etc.) and ergonomic aspects (number of trays, film sorter, daylight operation, etc.) of the printer.

The physical properties of the hardcopy are important not only for the image quality, but also for handling and archiving. The ISO 18939 standard describes test methods for measuring permanence of digital hardcopy for medical imaging. These include:

1. Evaluating physical properties
- Layer adhesion tested by (i) tape stripping and (ii) humidity cycling adhesion test
- Binder stability test for brittle failure
- Blocking and image interaction (in stacks of films)

2. Determining image permanence
- Dark stability (Arrhenius test)
- Evaluating light stability as failsafe test on a view box (3D in a light chamber at
- 40 °C / 20% rH and 3000 cd/m²)
- Measuring image spread (40 °C at 50% or 80% rH)

Hardcopy material has been developed for use with medical printers with proven diagnostic track records to provide the physical stability and image permanence required. For some of the new printing technologies entering the market place, this is not always clear. In particular, the porous receiver layers of aqueous inkjet systems have limited physical stability under elevated relative humidity conditions, and when they come in contact with liquids. In addition, inkjet prints with porous layers, as well as tone-based hardcopy prints, are potentially vulnerable to blocking in the tightly stacked storage typical of medical image archiving. Exposure to any of those conditions may thus result in partial or complete loss of the image information during handling or archiving.

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In conclusion

The introduction of PACS and digital patient records has not eliminated the demand for diagnostic hardcopy in many regions in the world. While many printing technologies are available today, not all comply with the quality standards required to produce a diagnostic-quality image on a transparent diagnostic film. Direct Thermal printers such as the DRYSTAR film and printer systems can deliver the image quality required for diagnosis.

Contrast resolution, spatial resolution and optimal viewing conditions are key parameters that define diagnostic quality, but the physical properties of the material are also important. Paper/opaque printing systems offer a lesser degree of value for diagnosis due to limited contrast resolution and use of half-tone printing.

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