Discussion of Fog Standards for Mammography

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Introduction

Standards for mammographic film/screen systems have been established for several decades. These standards have been established by national or local organizations for the purpose of ensuring quality in mammographic exams. One particular organization, The US Food and Drug Administration (FDA), enacted the Mammography Quality Standards Act of 1992 (MQSA). Similar regulatory agencies and regulations for mammography exist in many other countries throughout the world. These agencies provide training, certification, and specifications for many of the factors involved with mammography. These include standards for X-ray beam quality, X-ray dose, film sensitometric parameters, and film processing, among others. The specifications for these standards are based on "best practices" that are believed to result in high quality mammography.

Standards for Dmin values – (Base + Fog)

One standard, in particular, set specifications for minimum density (Dmin) for a mammographic film over the lifetime of the product. The Dmin value can be measured using film densitometers that are available in the mammography trade. Depending on the regulatory agency, these specifications can be as low as 0.25 to 0.30 over the lifetime of the product. The reasons for these values are based on mammography film responses over the last several decades. These are based on the assumption that if these Dmin values increase above a certain level during film aging, image quality deteriorates.

The reason for this assumption is that films that increased in Dmin values upon aging resulted in lower contrast. The contrast reduction seen was predominately in the lower portion (toe) of the characteristic curve. This lower toe contrast affected visualization of low-contrast objects, such as microcalcifications, but lower toe contrast occurred in breast tissue as well. Also, increased silver fog increased film granularity, which would result in higher film noise. The combination of lower film contrast and higher film granularity resulted in lower image quality.

Addition of blue dye to the support also increases film Dmin values. However, the resulting higher Dmin does not have adverse effects on image quality as described above. Why higher blue dye in the support actually improves image quality even with higher Dmin values will be described.

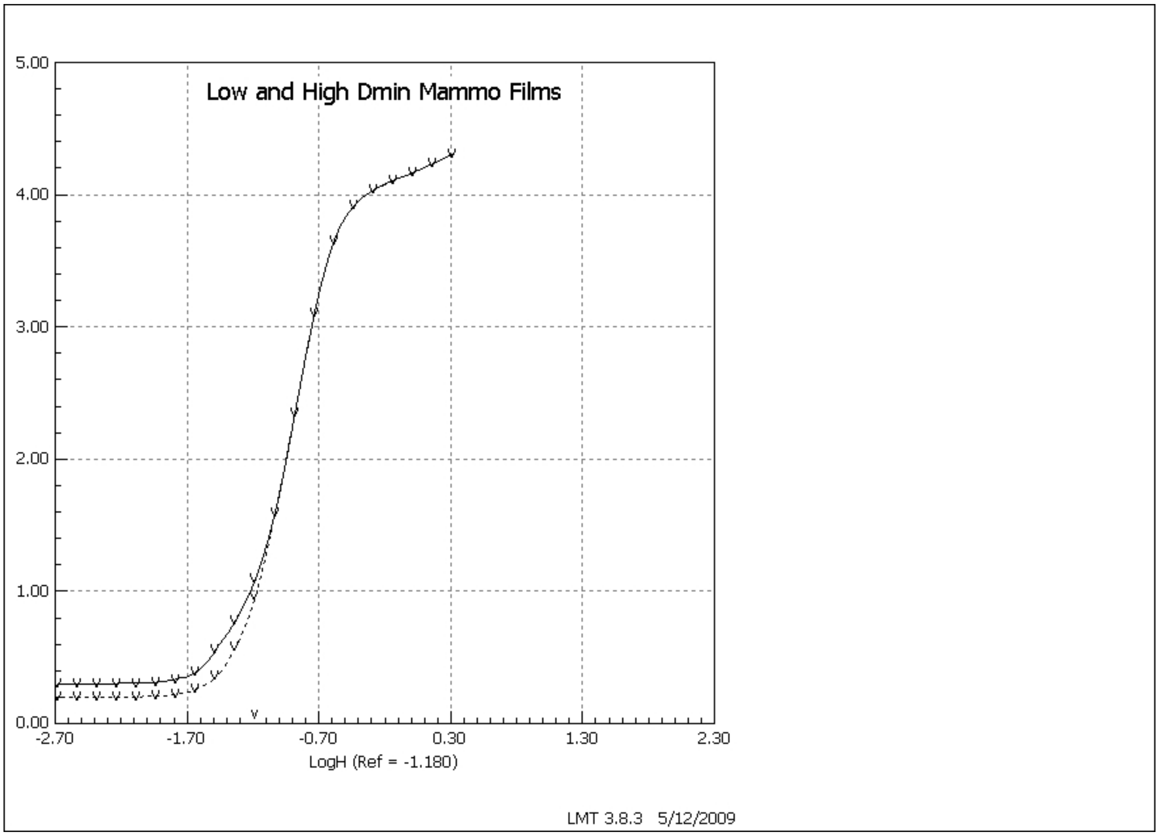


Figure 1. High and low Dmin mammography films.

Figure 1 shows sensitometric curves for mammography films with high and low Dmin of older emulsions as a result of increased silver fog. When the Dmin increases, contrast in the lowest density portion (toe region) pulls out or decreases. This has the effect of reducing visualization of lower density objects such as microcalcifications.

Early Mammographic Films

Mammography examinations depend upon films that provide high contrast in order to visualize normal and diseased breast tissue that are relatively close in X-ray attenuation. Early mammography films were manufactured using polydisperse silver halide grains, and they depended upon various chemical addenda and high iodide content to produce an effect called "infectious development" to produce a film with high contrast. The result of this was a film that had undesirable process sensitivity and high film granularity. Figure 2 shows an example of such an emulsion.

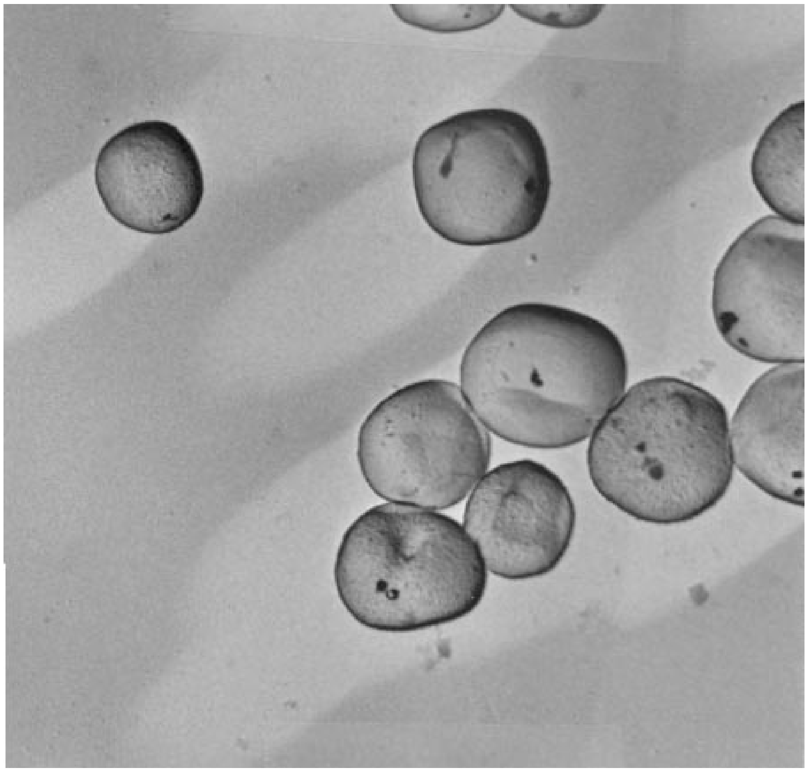


Figure 2. Early mammography emulsion.

Silver halide emulsions, such as seen in Figure 2, were difficult to make morphologically clean and were polydisperse in grain size and depended on infectious development to achieve high contrast. Also, because of the dispersity in grain surface area, it was difficult to chemically sensitize these grains, resulting in higher-than-desirable silver fog and film granularity.

Advances in Emulsion Technology

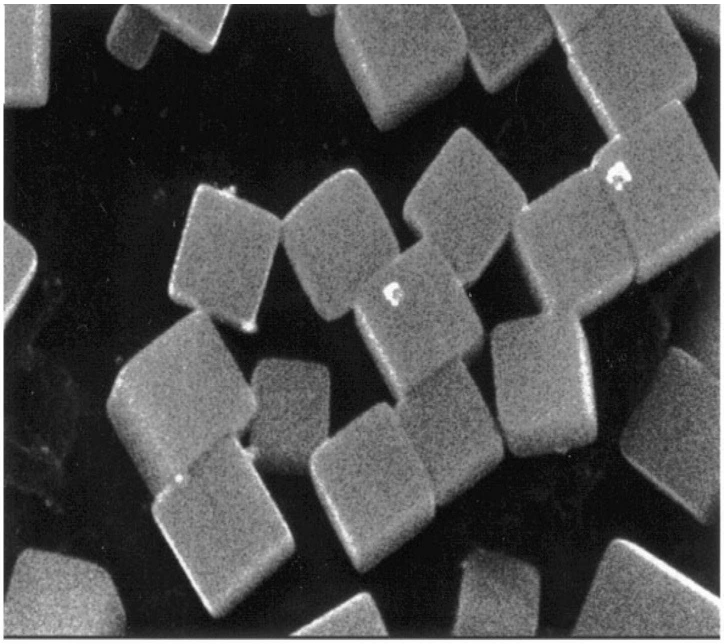


Figure 3. Modern cubic emulsion grains for mammography.

More recent mammography emulsions have been manufactured to provide grains that are much more monodisperse in grain volume and surface area. As a result, these grains are much easier to chemically sensitize, and they are inherently higher in contrast. The net result is that there is no longer a need to use chemical addenda or high iodide levels to achieve the contrast needed, and processor variability is greatly reduced. The more modern mammography emulsions have higher contrast, lower fog, and result in lower processor sensitivity. When fog does increase as a result of exposure to cosmic radiation, Dmin will increase, but contrast (particularly toe contrast) is not decreased. Also, there is little to no increase in film granularity as a result of fog formation.

Blue-Tinted Support in Mammographic Films

Radiographic films have been coated on blue-tinted support for many years, although the role that the support plays in the visual process of viewing a radiographic film is not well understood.[1] We have recognized that increased levels of blue tinting dyes added to the support or in a layer coated over the support can result in improved visualization of the radiographic film. The reason for this improved visualization can be attributed to a number of factors. These include:

1. Limiting the amount of transmitted light hitting the eye reduces glare. Increasing the amount of tinting dye reduces the amount of glare.
2. Limiting the wavelengths of light hitting the eye reduces polychromatic glare. This principal is used in tinted sunglasses. Limiting the range of wavelengths incident to the eye reduces the amount of polychromatic blur.

3. Increasing the amount of blue colorant in the film improves visual performance by enhancing the scotopic response of the eye.

Recent understanding of the role of lighting in enhancing visual performance by enhancing the scotopic response of the eye has been done by Dr. Ed Berman and colleagues at the University of California at Berkeley, Lawrence Livermoore Laboratory.[2] This understanding has been applied to many areas of lighting, such as street lighting,[3] light bulb design, and even viewing of soft copy display of X-ray imaging.[4] This understanding takes into account the following factors:

1. The human visual response of the eye involves both rods and cones. Cones are involved in photopic imaging, which is responsible for viewing under high luminance or daylight conditions. It also is involved in imaging fine detail and chromatic (colored) and detecting differences in hue. Rods are involved in scotopic imaging, which is responsible for viewing under low levels of luminance. Scotopic imaging is involved in night vision and is achromatic (black and white) and useful for detecting differences in intensity.
2. The cones are most receptive to green light at a wavelength of 555 nm, while rods are most receptive to blue-green light at 507 nm. Light meters and photometric devices are exclusively calibrated to the cone spectral sensitivity known as the "photopic response." As a result, the light output of lumens is rated only in terms of its photopic content, and to date, the rod spectral sensitivity, known as the "scotopic response," has generally not been considered of relevance for visual response.

Effect of Enhanced Scotopic Content on Pupil Size

The Berkeley researchers have determined that for conditions of full-field viewing and light levels typical of building interiors, the predominant spectral determinant of the pupil aperture is *scotopic rather than photopic.* Although in general, increases in light level will cause decreases in pupil size, white light whose spectral distribution is weighted more in the blue-green (scotopically enhanced) will be more efficient in contracting the pupil than white light, which is relatively deficient in blue-green composition. Because most of us have some imperfections in the lens of our eye and the imperfections cause optical aberrations, visual performance is generally improved with smaller pupil size, even for light levels typical of building interiors. At reduced light levels, as would be recommended for mammographic viewing, the effect would be even greater.

This led the Berkeley/Abratech research team to propose that reducing pupil size via shifting spectral distribution toward higher scotopic content could compensate for any reduction in visual performance caused by reducing light levels. Viewing under lower light levels is generally the accepted mode for viewing radiographic film and soft display. Thus, these reported observations have relevance in radiography.

One well-known visual performance factor that demonstrates the Berkeley proposition is depth of field, which decreases as pupil size increases. The research findings demonstrate that by replacing the original illumination by modified illumination, which is scotopically enhanced, depth of field can be maintained but at a lower light level. Again, radiographic viewing conditions at lower light levels would tend to increase pupil size, while illuminants with enhanced scotopic content would result in smaller pupil sizes. Smaller pupil sizes at the same level of luminance results in better visual performance [5]

Effect of Enhanced Scotopic Content on Glare

Berman et al. have also studied the relationship between glare and spectral distribution.[6] They found that a scotopically enhanced source produced less glare discomfort when compared to a scotopically deficient source, contrary to expectations. Glare is a distracting influence in radiographic viewing and can result in poor visual performance and eye fatigue.

Effect of Enhanced Scotopic Content with Observer Age

Berman also reports the effect of visual response as the observer ages. As the eye ages, there is a tendency for the lens to become yellow.[7] This, again, will influence the relative perception of scenes lighted with light sources of different spectral distributions. In radiographic viewing, yellowing of the lens will affect the image tone and visual contrast of the radiograph. In order to compensate for this increased yellowness of an older lens, it may be beneficial to increase the blue tint of the radiographic film support.

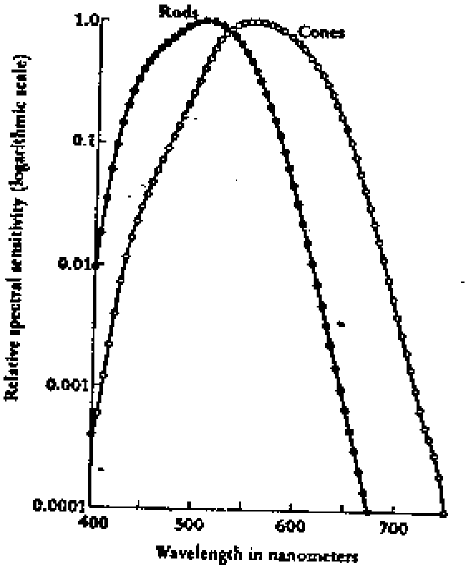
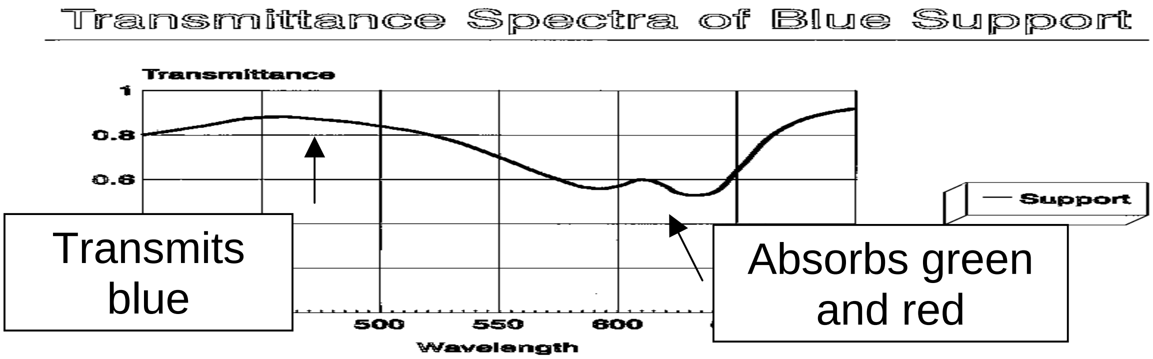


Figure 4. Spectral sensitivity of rods and cones of the eye.

Blue-tinted radiographic polyethylene terephthalate (PET) support contains a dye that absorbs light in the red region of the spectrum and transmits light in the blue region of the spectrum.



Transmits blue

Absorbs green and red

Figure 5. Transmittance spectra of blue-tinted PET support.

As can be seen in Figure 5, blue-tinted PET support results in higher transmittance in the blue region of the spectra 400–500 nm than in the green and red regions (500–700 nm). This increased transmittance in the blue region is responsible for stimulating the rods (scotopic vision) of the eye rather than the cones. The increased scotopic vision is responsible for detecting differences in intensity. Differences in intensity in a radiograph are the same as film contrast. Thus, enhanced scotopic content in a film improves visualization in film contrast.

A metric for measuring the amount and spectral distribution of transmitted light is called CIELAB and is an international standard for measuring color. CIELAB L* or luminosity is a measure of how much light is transmitted from an object to the eye. L*, a*, and b* measurement techniques are described by Billmeyer and Saltzman.[8] The measurements of a* and b* were developed by the Commission Internationale de L'Esclairage (International Commission on Illumination).

-B* is the metric that determines the intensity of blue light transmittance. The more negative the number, the greater the amount of blue light transmitted from the film to the eye.

The noted CIELAB a* and b* values are indications of image tone as viewed by transmission. The values were determined by CIELAB standards for spectra recorded from 400 to 700 nm using Cool White as the standard illuminant. The b* value is a measure of the yellow-blue color balance, and the a* value is a measure of the green-red color balance. A difference of at least 0.7b* units or 0.2a* units is considered to be a noticeable difference for a standard observer.

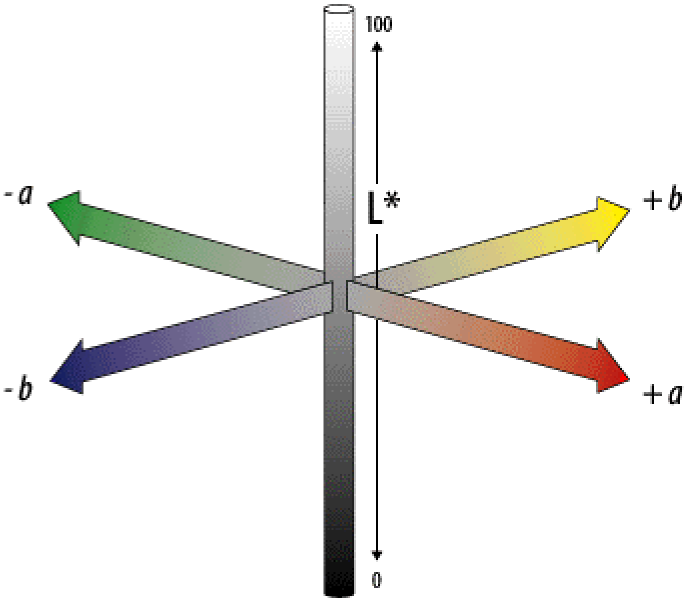


Figure 6. CIELAB measurement of color.

The central vertical axis represents lightness (signified as L*) whose values run from 0 (black) to 100 (white). A* is the measure of the red-greenness of the hue, while B* is the measure of the yellow-blue component of the hue. A -B* value is what we anticipate for improving scotopic response of the eye for viewing radiographic films.

Experimental Results

Table 1. Effect of increased blue tinting dye vs. fog in a mammographic film

Part	Fogged Silver	Blue Dye	Dmin	Contrast	Image Tone
1	0	0.0	0.227	4.3	-8.7
2	5	0.0	0.261	4.3	-8.8
3	10	0.0	0.295	4.2	-8.7
4	20	0.0	0.360	4.2	-8.5
5	0	0.5	0.240	4.3	-9.5
6	0	1.0	0.258	4.3	-10.9
7	0	2.0	0.285	4.2	-13.1

Table 1 shows, that for mammography films, increases in fog (Dmin) can be accomplished by either increasing the amount of fogged silver or by adding increased levels of a blue tinting dye (Macrolex 6T3 dye). Increasing the amount of fogged silver is similar to what would happen to a film under higher temperatures or increased age of a film. Increased fogged silver does not improve image tone but, rather, results in a warmer image tone at the highest coating levels. Increasing blue dye levels increases fog levels to a lesser degree then fogged silver but results in significant improvement in image tone. Parts 3 and 7 have similar Dmin values, but Part 7 has very significantly colder image tone (B* more negative). Mammographic films today generally have image tone that approach -9, but the potential exists to an achieve image tone of -13 with only slightly higher gross fog values.

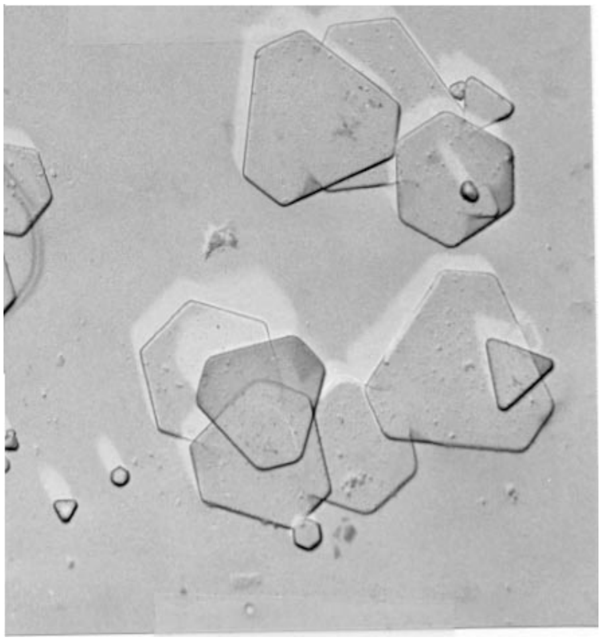


Figure 7. Tabular emulsion grains for general-purpose films.

Figure 7 shows tabular emulsion grains for general-purpose films. As can be seen, these emulsion grains are not as morphologically clean as modern mammography emulsions and, as a result, do not have as high contrast.

Table 2: Effect of increased blue tinting dye vs. fog in a general-purpose radiographic film

Part	Fogged Silver	Blue Dye	Dmin	Contrast	Image Tone
1	0	0.0	0.21	2.99	-7.8
2	2	0.0	0.354	2.88	-7.7
3	5	0.0	0.493	2.66	-7.6
3	10	0.0	0.730	2.33	-7.5
4	15	0.0	0.910	1.78	-7.2
5	0	0.5	0.228	2.94	-8.9
6	0	1.0	0.249	2.95	-10.4
7	0	2.0	0.279	2.93	-12.9

Table 2 also shows that, for general-purpose films, increases in fog (Dmin) can be accomplished by either increasing the amount of fogged silver or by adding increased levels of a blue tinting dye. Increased fogged silver does not improve image tone but, rather, results in a warmer image tone at the highest levels coated. Again, increasing blue dye levels increases fog levels to a lesser degree than fogged silver but results in significant improvement in image tone. Parts 2 and 7 have similar gross fog values, but Part 7 has very significantly colder image tone (B* more negative). General-purpose radiographic films today generally have image tone that approach -7 but the potential exists to achieve image tone of -13 with slightly higher gross fog values.

Proposal for New Fog Measurement in Mammography Films

In an attempt to control radiographic film quality, various regulatory agencies have issued standards for film base + fog levels. These values typically range from 0.25 to 0.30. These are based on the assumption that if these values increase above a certain level during film aging, image quality deteriorates. The reason for this assumption is that, historically, films that did not age well had silver fog values increase and contrast levels decrease, as the toe of the characteristic curve would pull out. Also, increased silver fog increased film granularity, which would result in higher film noise. The combination of lower film contrast and higher film granularity resulted in lower image quality. As was shown in the examples above, films with high base + fog values achieved by increased blue tinting dye did not lower film contrast or increase film granularity but, rather, increased image quality by enhancing the scotopic response of the eye.

I suggest that, rather than using absolute values of base + fog, one should consider other measurements of film performance that more accurately reflect the image quality of a film. These include the following:

1. Measure base + fog density and subtract film base density (available from the manufacturer). This would provide a measure of only the silver fog growth.
2. Measure base + fog values immediately after receiving and monitor density growth upon aging

New limits on film aging could be generated using these measurements, which would provide a better measurement of film quality without sacrificing the opportunity to improve image quality by enhancing the visual scotopic response.

Summary and Conclusions

Government and local regulatory agencies provide standards to ensure quality in mammographic examinations. One of these standards involves the measurement of base + fog or Dmin. Limitations on the absolute value of base + fog can be as low as 0.25 or 0.30 over the life of the mammographic product. The rationale for limiting the value of base + fog is that, historically, earlier mammography films that showed an increase in the base + fog measurement also had a lowering of film contrast and particularly lower toe contrast. This lower contrast negatively affected visualization of microcalcifications and other breast parenchyma. Also, increase in the base + fog measurement was accompanied by an increase in film granularity, which impacted the noise of the mammographic image.

The reasons for this increase in base + fog in early mammography films is that the emulsions used were not morphologically clean and depended upon chemical addenda to achieve high contrast. This is not the case with modern mammography emulsions that are much more morphologically clean and, as a result, are easier to sensitize chemically, which results in higher film contrast.

Radiographic films have been coated on blue-tinted support for several decades, but the understanding of why that was the case was determined empirically, and it was little understood as to why blue-tinted support was desirable in radiography viewing. Recent understandings in the field of lighting have led to a realization that by increasing the amount of scotopic content in the viewing illuminant, one could improve viewing performance of achromatic tasks under reduced light conditions. This is exactly what is involved in viewing radiographic images. Blue-tinted support contains dyes that allow for increased scotopic involvement of the visual process and improve visual acuity.

Measurement of base + fog is done using film densitometers available in the trade, but the measurement is the total of both the density of the base and any silver fog generated during manufacturing or upon film aging. It is the silver fog that is important for the performance of the film but only if it results in a lowering of film contrast. The density produced from the blue-tinted base is beneficial to viewing of the film image and not detrimental, as one might expect, due to the higher value of the base + fog measurement. Experiments were done demonstrating that higher base + fog values achieved, as a result of adding higher amounts of blue dye, improved subjective evaluations of image quality. Increase base + fog values by adding silver fog decreased the subjective evaluation of image quality. As a result, I recommend removing the base part of the base + fog and measuring fog only. This can be done by measuring total base + fog and subtracting the base from the measurement (base densities can be obtained from the manufacturer). Alternatively, base + fog can be measured immediately upon receiving fresh product from the manufacturer and measuring only the increase in base + fog based upon time rather than the absolute value of both.

By using these recommendations, one can ensure image quality in mammography, as the regulatory agencies are charged with and can provide for new mammography with higher levels of blue-tinted dyes that have the potential for improved image quality.

References

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