AAPM REPORT NO. 94

Validating Automatic Film Processor Performance

Report of AAPM Task Group 22

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Validating Automatic Film Processor Performance

Report of AAPM Task Group 22

Radiography and Fluoroscopy Subcommittee

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1. INTRODUCTION

Poor film processing affects both image quality and the amount of radiation a patient receives. The introduction of automatic film processors eliminated problems historically associated with manual processing such as development of film by sight, where the development time was dependent on the human observer and was very subjective. Automatic processors improved the consistency of film development by providing constant film development time and maintaining a constant developer temperature. In spite of these technological advancements, automatic film processing continues to be considered one of the most variable components of the imaging chain for a variety of reasons. Over the years, professional societies, industry, and government have addressed these concerns and expended considerable effort developing and refining quality control (QC) tests for film processing in radiology.[1,2,3,4,5,6,7]

Task Group 22 (TG22) of the American Association of Physicists in Medicine (AAPM) does not feel there is a need to address, once again, the general area of quality control. The members of TG22 agreed, however, that there continues to be a critical need for more specific guidance on how to validate the proper operation of automatic film processors. The members of TG22 represent academia, industry, government, and practicing medical physicists who deal routinely with both large and small facilities.

Although many large diagnostic imaging departments are transitioning to entirely digital environments, smaller offices, particularly those owned and operated by non-radiologists, continue to rely on screen-film image receptors and conventional film processing. As recently as October 1, 2004, only 5% of all mammography units in the United States were digital.[8] Film processing for the foreseeable future will continue to have a significant impact on the quality of film-based imaging. Even with the inevitable shift toward digital imaging, there are many medical facilities in the United States (such as small non-institutional facilities) and the rest of the world, especially developing countries, where film-based imaging will continue to be used for the foreseeable future.

Most processor QC programs assume that the processor has been optimized to provide the maximum film performance. However, most film manufacturers typically establish the film performance characteristics only for their product, specifying technical information only for their processors and chemical solutions (starter, developer, fixer). There is little practical guidance, when non-specified processors and chemical solutions are used, to help facility personnel optimize the processing of their film at their site before a QC program is established. Consequently, many facilities rely on processor service personnel to do this; and their knowledge, training, and experience in image quality may vary considerably.

Processor optimization is also complex due to the availability of multiple combinations of film types, automatic film processors, chemical solutions, and recommended developer temperatures.[9] This is further complicated by film and chemical solution manufacturers' recommendations and claims of equivalency, i.e., an independent chemical solution manufacturer may state that its chemical solutions are equivalent to the film manufacturer's chemical solution specifications, or that a specified film when processed with its chemical solution will result in equivalent film optical densities. Many facilities "mix and match" film, processor, and chemical solutions from different manufacturers in an attempt to save money, without understanding the impact this may have on image quality.

Even if a processor has been set up initially in accordance with the film manufacturer's recommendations, there are many reasons why the processor may deviate over time. The facility may not have a QC program in place, the facility may have an inadequate QC program, the

operator may not be a qualified technologist, or may not be sufficiently knowledgeable to identify and differentiate processor problems from x-ray problems. Even large institutional facilities are not exempt from such problems, since many outsource processing services. The qualifications of personnel tasked to identify and to troubleshoot problems vary considerably.

This report provides the practicing medical physicist with a realistic, practical protocol for validating automatic film processor performance using specified film, light sensitometers, and densitometers. For purposes of this report, validation is defined as meeting the film manufacturer's film densities. This will be done by establishing and comparing film densities from films processed both in a reference (benchmark) processor and in the site processor. In certain situations it may be extremely difficult to establish a reference processor; for those situations an alternative procedure has been provided.

2. MATERIALS AND EQUIPMENT

2.1 The Standard Reference (Benchmark) Processor

One processor should be identified as the benchmark processor, thereby serving as the standard reference processor. This processor should have daily QC testing performed, and should be known to be operating according to the film manufacturer's recommendations. Selection of such a processor is difficult, but this benchmark processor is essential. Appendix A contains specific methods to establish processor equivalency with manufacturers' recommendations, appendix B provides steps for calculating processing speed, and appendix C describes how to measure film development time.

2.2 Alternative to the Standard Reference (Benchmark) Processor

If a reliable processor is not available to be designated as the standard reference (benchmark) processor, then an alternative method is to maintain a "running average"[10] of processing speeds and other relevant metrics such as contrast from a number of sites which are known to be following a film manufacturer's recommended processing specifications. These processors should all be evaluated with the same sensitometer and film from the same emulsion batch. This can only be done when there are site processors known to be using the correct chemical solutions and operating according to the film manufacturer's recommendations.

2.3 Chemical Solutions

The chemical solutions used in the automatic film processor should be those specifically recommended by the film manufacturer. The starter, developer, and fixer solutions should be stored properly, i.e., according to the manufacturer's recommendations, and used before their expiration date. In order to assure that these solutions have been mixed properly, it is preferable to mix these solutions on-site rather than using pre-mixed solutions. Pre-mixed solutions can be used, but there must be some assurance that these have been mixed properly. A test to determine processing equivalency for different chemical solutions is described in appendix A. Relevant metrics, such as film development time (film immersion time) and developer temperature, must be routinely measured and recorded—and periodically validated for accuracy—since the performance of the film in these chemical solutions will depend on the development time and temperature.

2.4 Control Film

Two films should be used to evaluate a processor: a standard control film that is always used in all processors, and the film used routinely in the site processor, which may be a different type than the standard control film. Film from the same emulsion batch should be selected for both the control film and the site film. A minimum of one box of each type of film should be selected and put aside for use in this evaluation. *This will minimize batch-to-batch emulsion variability.*

2.5 Light Sensitometer

The light sensitometer selected should have 21 steps, with each step having a log relative exposure increment of 0.15. At least two light sensitometers, with the light emission spectra nominally matched with the film's spectral sensitivity, either single or double emission, should be matched by film optical density at specified steps. For these light sensitometers to be considered equivalent, film exposed to these two or more sensitometers should be the same type of film, from the same emulsion batch, and processed in the same processor at approximately the same time. They should also be read with the same densitometer. The resultant film optical densities should be within 0.02 in the base + fog (B+F) region of the film, and within 0.05 over the entire characteristic curve for specified sensitometer step numbers. One of these sensitometers should be designated as the benchmark sensitometer for use as the reference standard; the others should be designated as field sensitometers. The second sensitometer may also serve as a backup, in case the benchmark sensitometer fails.

2.6 Densitometer

A densitometer accurate to within 0.02 optical density, using an optical density calibration film traceable to the National Institute of Standards and Technology (NIST) should be used.[11]

2.7 Thermometer

An electronic or alcohol thermometer, accurate to within 0.1 °C should be used. *Mercury is a silver halide sensitizer; consequently, mercury thermometers should not be used, since mercury contamination from a broken mercury thermometer would be very difficult to remove.*

2.8 Light-tight Box

A light-tight box should be used for transporting undeveloped control film and undeveloped site film between the site and the benchmark processor.

3. PROTOCOL

3.1 Preparation

The benchmark processor, or the "running average" processors used in the alternative method, should be set up according to the film manufacturer's recommended specifications. As a minimum, this requires using the film manufacturer's recommended chemical solution(s), replenishment rates, specified film development time, and developer temperature. Appendix A lists a method for evaluating equivalent film performance on other manufacturers' chemical solutions.

This properly operating benchmark processor should then be characterized to establish baseline performance values and realistic control limits for the control film, sensitometer, and densitometer selected. The baseline QC data should be collected over a period of time, control charted, and periodically evaluated. Since most light sensitometers expose the film to incremental quantities of light, corresponding to an increase of 41%, 1.41, the square root of 2, or log rel E of 0.15, the density versus sensitometer step number curve approximates the optical density versus log relative exposure curve (Figure 1). As a minimum this should include film densities corresponding to the toe region of the film's characteristic curve (usually referred to as base + fog), the speed density corresponding to a net density above base + fog of 1.00, and a higher density. It is preferable to plot the entire film optical density versus sensitometer step number curve initially, and then to select the appropriate sensitometer step numbers for routine QC testing.

As stated earlier, QC testing of automatic film processors is beyond the scope of this report. Fortunately there is extensive information on processor quality control available from the previously cited literature.[1,2,3,4,5,6,7] In addition, representatives and manufacturers of film, chemical solutions, and quality assurance (QA) test equipment are also excellent sources for obtaining such information.

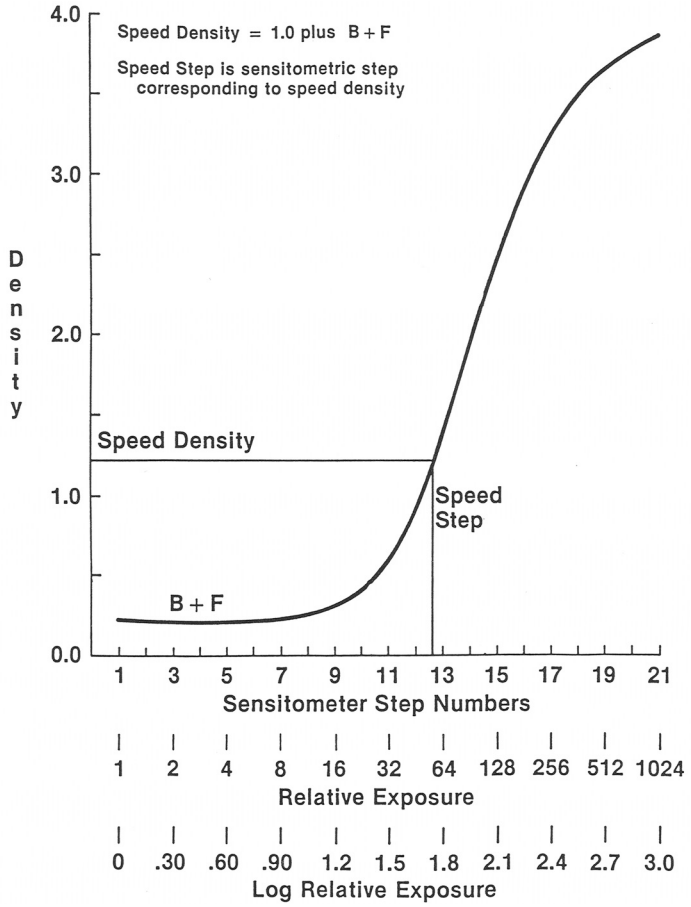

Figure 1. The density versus sensitometer step number curve approximates the optical density versus log relative exposure curve. (Reprinted from "Results of Federal and State Studies on Film Processing," fig. 1, p. 30, by O. H. Suleiman in *Film Processing in Medical Imaging*. A. G. Haus (ed.) with permission from Medical Physics Publishing.)

3.2 Establishing the Benchmark Processor

Read each step in its entirety before conducting it. Discussions on the procedure are in *italicized* type.

3.2.1 Verify that ambient darkroom fog levels have been determined and film can be safely handled in the darkroom. Darkroom fog levels greater than 0.05 can inadvertently interfere with the sensitometer exposures, and need to be systematically eliminated. This can be done either by performing a darkroom fog measurement[1,2,3,4,5,7,12] or by checking site QA records. Fog levels should be less than 0.10 for a 2-minute darkroom exposure.

3.2.2 In the darkroom, select a sheet of your control film, expose each film twice sensitometrically, once on the left side, once on the right side. Wait a consistent time between sensitometric exposures (20 seconds being a reasonable period of time) and wait a similar amount of time prior to feeding the film into the processor. Feed the film into the processor consistently in the same way: from the left side, the center, or the right side of the feed tray.

Waiting the same amount of time between sensitometric exposures will minimize latent image instability effects.[13,14] *Feeding the film into the processor the same way each time minimizes differences due to inherent processor variability, such as subtle temperature differences within the developer tank or subtle changes in concentration of the chemical solution due to mixing, depletion, and replenishment.*

3.2.3. Record the time the film was developed on the processed film using a permanent ink marker. Using the calibrated densitometer, read and record the film optical densities. Either plot the entire curve or record representative film optical densities in your quality control log and chart.

The two separate sensitometric exposures are made to ensure that the light exposure is consistent. If there is a significant difference in the optical densities, usually greater than 0.04 for the base + fog region, or greater than 0.10 for the linear portion of the film's characteristic curve, the test needs to be repeated. Because of differences in the inherent variability of sensitometers, film emulsion, exposure conditions, and the human user, differences greater than expected for your set of equipment and conditions should be investigated. Instead of two exposures, you may prefer to make three or four exposures on each film and use the average for better statistical confidence. This will add some time to the test but increase the statistical confidence of the measurement.

At this time, other benchmark tests not limited to the processor but associated with the entire imaging system should be performed and maintained for future troubleshooting. These tests may be film images of a standard radiographic test phantom and critical metrics such as geometry, radiation output, radiation quality, grid, and image receptor (type of film, screen). This documentation should also be kept in your QC notebook. The reader is once again referred to references 1, 2, 3, 4, 5, 6, and 7 for more detailed information on these QA and QC tests.

3.3 Site Processor Evaluation

Once you have established your baseline performance standard, using either the standard reference (benchmark) processor data or the running averages data from a composite set of processors, you can then evaluate the site processor by relative comparison.

3.3.1 Once again, this time for the site processor, verify that ambient darkroom fog levels have been determined and film can be safely handled in the darkroom. (*See step 3.2.1 in the previous section,* Establishing the Benchmark Processor.)

3.3.2 Verify that the site processor has attained the proper operational temperatures, and is operating properly. This means that the developer and fixer solutions have been properly prepared, tanks completely filled, and developer temperature, base + fog, and speed density have been measured and determined to be within QC limits.

3.3.3 Designate a box of film to use for the site. This should be the same film type, and preferably from the same emulsion batch, that the site uses for their QC testing for the site processor being evaluated. *This is done to minimize batch-to-batch emulsion variability.* Record information such as the film type, emulsion batch number, expiration date of film. *This may be useful for future troubleshooting*.

3.3.4 Place at least two sheets of the unexposed site film into your light-tight box for transporting back to your benchmark processor. *These two films, one being a backup sheet, are to be later exposed to your matched sensitometers and processed in the benchmark processor.*

3.3.5 Film should be handled quickly in the darkroom environment to minimize exposure to darkroom conditions.

3.3.6 (*This is same as step 3.2.2 in previous section,* Establishing the Benchmark Processor.) Select a sheet of your control film; expose each film twice sensitometrically, once on the left side, once on the right side. Wait a consistent time between sensitometric exposures (20 seconds being a reasonably period of time) and wait a similar amount of time prior to feeding the film into the processor. Feed the film into the processor consistently in the same way: from the left side, the center, or the right side of the feed tray.

3.3.7 Once the sheet of control film has been processed, visually verify that each film has properly exposed sensitometric strips. If not, repeat the test. If acceptable, record the time of the test, site location, processor information, film information (control and film type), and the developer temperature (whether measured or indicated) on the sheet of film using a permanent ink marker.

3.3.8 Repeat steps 3.3.6 and 3.3.7 using a sheet of the site's film.

3.3.9 Measure and compare the film optical densities for each film type, control film, and site film processed in the site processor. The comparison should be between several representative sensitometer step numbers. If there is a significant difference in the optical densities for each film type, usually greater than 0.04 for the base + fog density or greater than 0.10 for the speed density, the test needs to be repeated.

3.3.10 Verify that both films have the necessary information recorded on them with permanent ink markers, and put them into a designated folder for further evaluation.

3.3.11 Processing speed for the site processor should be calculated using your control film and by following the procedure specified in appendix B.[15,16]

Determining processing speed is preferable to measuring the film optical density and comparing the difference with a known reference density associated with a sensitometer step number. Film density difference will not reflect the difference in relative exposure associated with the two densities, since the relative exposure difference depends on the slope of the characteristic curve of the film. A film with a low contrast index will require more relative exposure for a given density change than a film with a high contrast index, or stated another way, for a known log relative exposure difference, such as that between two consecutive sensitometer step numbers (Δlog rel E ~ 0.15), the low-contrast film will have a smaller change in film density than a higher contrast film.

Processing speed is a simple, single metric, and will verify if the processor is developing the film to a reference film optical density. A value of 100 is considered equivalent to the film manufacturer's processing environment. A processing speed greater than 120, or less than 80 suggests significant deviation from the film manufacturer's recommendations.

The 20% action levels suggested above are used in the inspection program of the federal mammography program[17] and are derived from a base of 250 to 300 light sensitometers that are annually tested directly against film manufacturers' recommended processing conditions. As many as 10,000 mammography facilities have been inspected annually by 250 to 300 inspectors. The 20% action level is large, incorporating uncertainties associated with the inherent variability associated with a wide geographic region, and how these conditions affect the sensitometers, densitometers, and large supply of control film.[18] Additionally, these action limits allow for normal daily site processor variations. It is possible that the variability associated with a few sensitometers and a few boxes of film will be less and your own experience with dedicated equipment may allow you to select tighter action levels.

Film contrast using a light sensitometer should be evaluated with caution! *Film contrast determined from light sensitometer exposures may not accurately reflect the actual contrast obtained clinically using x-rays and light*

from different types of intensifying screens. Factors such as x-ray versus light exposure, the spectra of light or x-rays used, the effects of reciprocity law failure, film sensitivity to these sources of exposure make standard comparisons difficult.[19] Regardless of these limitations, a relative comparison of contrast by plotting and comparing the relative curves for both your control film and the site's film, processed both on site and in the benchmark processor, is valuable information.

Contrast measured using a light sensitometer may have limitations, since it is not an absolute measure of contrast and may not represent the clinical environment; but it is still very useful information. The light spectra from a light sensitometer may not accurately represent the actual spectra from an intensifying screen, which will also include some x-rays. Therefore, comparing film contrast between different film types using only a light sensitometer should never be considered as the definitive test. Using the light sensitometer to establish relative processing benchmark metrics is extremely valuable and useful, but since light sensitometers are not standardized in terms of absolute light output and vary among sensitometers in terms of spectra, intensity, and exposure time, they should not be considered primary reference standards. The light sensitometer is a valuable processor control tool; it is not intended to compare and evaluate different films exposed in a clinical environment objectively.

3.4 Processing of Site Film in Benchmark Processor

3.4.1 Verify that the processor is operating within limits.

3.4.2 Take the light-tight box into the benchmark processor darkroom. Using a sheet of the site's film, a sheet of your control film, and the benchmark sensitometer, repeat steps 3.3.6 through 3.3.11 of the protocol in section 3.3, Site Processor Evaluation.

4. EVALUATION OF TEST FILMS

The four processed sets of film need to be compared and evaluated. They are: (1) the control film processed in the site processor; (2) the control film processed in the benchmark processor; (3) the site film processed in the site processor; and (4) the site film processed in the benchmark processor.

Plot the four sets of curves, density versus sensitometer step number. Label each set of curves with the film type, processor, and time and dates processed.

Processing speed is a simple, single performance metric that measures processing activity, which depends on chemical solution concentration, developer temperature, and time the film has been in physical contact with the developer solution. It compares the activity at the speed density, defined as the net density of 1.00 above base + fog. Traditionally, speed density has

been defined as a net density of 1.00, but comparisons can also be performed at different densities. It is possible for processing speeds to differ if compared at different densities. A better, more comprehensive evaluation of processing requires an evaluation of the entire curve, and densities should be compared over the entire range of clinically useful densities, the range of film optical densities which correspond to the range of useful densities associated with a clinical film, which clearly is not limited to a density of 1.00.

Film contrast is usually specified as the density difference associated with the log relative exposure difference for two different exposures. Contrast may be determined for any two sensitometer steps; as the average gradient, a term used by the film industry for many years (see appendix A for the formal definition of average gradient); or may be plotted as a density difference for each consecutive pair of sensitometer step numbers. Since most sensitometers incrementally expose the film to a log rel E of 0.15, the light gamma, using the light sensitometer, is defined by the following:

$$\gamma_L = \frac{\text{Density at sensitometer step}_{(x+1)} - \text{Density at sensitometer step}_{(x)}}{0.15}$$

where x *is the sensitometer step number, and* (x + 1) *is the next consecutive sensitometer step. Plotting a light gamma versus film optical density curve will more visually demonstrate the changes in film contrast at different film densities (see Figure 2 on page 9 and the discussion in section 5.3.1).*

Base + fog values are relatively insensitive to minor processing differences, and are usually characteristic for a specific film type. It is not unusual to have two very different base + fog values for two different films. Differences in base + fog greater than 0.04 for the same film type and emulsion batch should be investigated. Changes of this magnitude may be due to aging of the film and to environmental factors such as exposure of the film to extraneous light or chemical vapors. Usually such effects on base + fog will result in much greater changes in the higher film densities, especially those densities along the linear portion of the characteristic curve.

5. QUESTIONS AND ANSWERS BY SUBJECT

5.1 Benchmark Processor

5.1.1 **Question:** What is a benchmark processor?

Answer: This is a processor designated as the reference standard. It needs to be accessible and highly reliable. It should be a processor at an installation in a well-run site, one that is maintained on a daily basis and for which adequate quality control is maintained.

If a reference benchmark processor is not available, then the running average from a set of automatic film processors conforming to the film manufacturer's recommended processing specifications is a practical alternative.

5.1.2 **Question:** Why do I need a benchmark processor?

Answer: The benchmark processor is your *de facto* reference processor. Due to the proprietary nature of chemical solutions and film emulsion composition, a direct absolute standard for processing is not practical. Using a benchmark processor is the most practical alternative.

5.1.3 **Question:** How reliable is the benchmark processor?

Answer: The reliability of the benchmark processor is only as reliable as the level of confidence in the film quality, chemical solution quality, and accuracy of specific technical processing metrics such as film development time and developer temperature. It is also dependent on its quality control. Film and chemical solution manufacturers will often provide you with the necessary technical support to assure that your films are being developed properly. However, the quality of such information varies, and although automatic film processor setup, according to the film manufacturer's recommendations, is approximately the same, differences do exist for films processed in different chemical solutions. You need to be aware of the potential for such differences, and determine what these differences are for the types of clinical films processed in your site processors.

5.1.4 **Question:** What if I do not have access to a benchmark processor?

Answer: Sometimes it simply is not possible to have access to a dedicated reference benchmark processor. A practical alternative to the benchmark processor, especially for the consulting physicist with access to multiple facilities, is a set of automatic film processors that are known to be operating properly, located in various clinical settings. This is somewhat subjective, but will depend on your confidence in the facilities' QC programs, and history of maintaining reliable QC records documenting that each processor has been operating within established QC limits. This set of processors should be limited to those processors, each of which is known to be operating according to the film manufacturers' recommendations, or equivalent.

5.2 Chemical Solutions

5.2.1 **Question:** What does manufacturer's recommended processing specifications mean?

Answer: If the film manufacturer's recommended processing specifications are followed, performance of the film, i.e., resulting film optical densities and derivative metrics such as contrast for a known film, are considered the standard for comparison.

5.2.2 **Question:** Does adherence to these recommended specifications assure that the film will result in the proper film densities?

Answer: Not necessarily. Generally, for a given film, following the manufacturer's recommended processing specifications, or equivalent, assumes that the film or chemical solutions meet the manufacturer's specifications. These products, however, are subject to manufacturing errors, although rare, and are also exposed to a host of environmental conditions, including transportation and storage. After leaving the manufacturer's control, these products are still susceptible to improper environmental conditions. They are also susceptible to possible human errors associated with mixing the solutions, either by the facility or the local chemical service. Whether the chemical solution has been improperly mixed, accidentally contaminated, or intentionally diluted by a local chemical service or individual, the effect is the same. Film and chemical solutions are also subject to aging beyond the expiration date, which can easily be overlooked. Some chemical solution manufacturers have not always had expiration dates on chemical solutions because of the assumption that they will be used relatively quickly. Storage conditions such as relative humidity, low or high temperatures, and exposure to potential contaminants can also affect the quality of chemical solutions. Films processed in these compromised environments, even if they adhere to the manufacturer's labeled product specifications, may not perform as the manufacturer intended.

Another source of confusion is when manufacturers' recommendations are not known, and chemical solutions from chemical solution companies not affiliated with the film manufacturer may or may not claim equivalency. How equivalency is determined is also subject to different and sometimes confusing criteria. A test to determine processing equivalency for different chemical solutions is described in appendix A.

5.3 Film

5.3.1 **Question:** What are the advantages and limitations of using film?

Answer: The advantage of film is that it represents overall system performance more accurately than any other intermediary metric, especially if it is the same type of film used clinically. It incorporates the effect of all of the components of the processing system. If the film performs as expected, i.e., the resulting film densities are the same as if the film had been developed in the film manufacturer's specified processing environment, then it is assumed that the processing environment is equivalent.

The limitations of film are that it is extremely susceptible to changes in the latent image due to time, temperature, and other environmental conditions, and also susceptible to manufacturing differences among batches. This is why film from the same batch should always be used to eliminate batch-to-batch variability.

Measuring film contrast using a light sensitometer may not be indicative of the actual contrast obtained with an x-ray source and exposure to light from an intensifying screen. Consequently, interpretation of changes in contrast may be related to the processing quality, but may not represent the true contrast characteristics of a film when it is used in a clinical environment. When evaluating films for radiographic speed and contrast, actual clinical conditions should be used, i.e., using the actual intensifying screen and x-ray beam. Evaluating processing is not the same as evaluating the entire imaging chain. Figure 2 graphically shows how the same film, processed in the same processor, will provide different measures of contrast depending on the type of light to which it has been exposed. The test films were exposed using x-ray sensitometry, a commercially available light sensitometer using an electroluminescent panel (ELP), and a prototype light source which more closely approximated intensifying screen light spectra.

5.3.2 **Question:** Is it acceptable to use mammography film for control film when evaluating a processor that routinely processes only non-mammography film, or vice versa?

Answer: This is a conditionally acceptable alternative only when it is not possible to use the same film type as used in the site processor, especially when the processor is performing very poorly. Very poor processing will result in poor quality films, regardless of the film type.

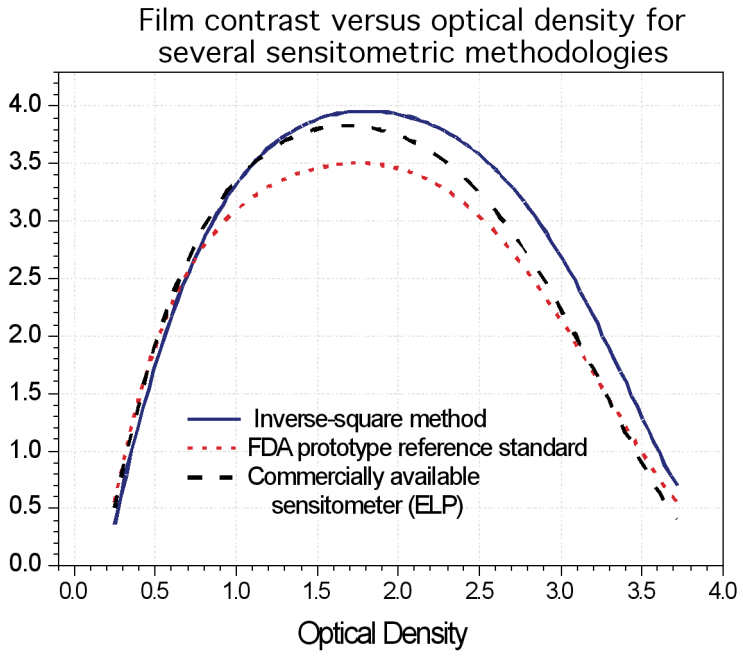

Figure 2. Graph showing the difference among two different types of light sensitometers and inverse square sensitometry using x-rays. (Reproduced from reference 20, *Med Phys* vol 27, issue 5, 2000, with permission of AAPM.)

Differences do exist because each film type performs slightly differently in different chemical solution environments. Predicting the magnitude of this difference for use in the field is extremely difficult, because of the many different types of film, chemical solutions, and processors available. It is best to use a film type that is the same, or very similar to, the type of film routinely used, which is why the protocol in this report suggests evaluating both your control film and the film used in your site facility in both the site processor and the benchmark processor.

5.4 Light Sensitometer

5.4.1 **Question:** Do all sensitometers perform the same?

Answer: No, unlike radiation measurements where the radiation output and quality can be determined with standard instrumentation, light sensitometers are not standardized, and the endpoint, the image on the film, more specifically film optical densities, are highly dependent on the film itself and the processing environment (chemical solutions, developer immersion time, and developer temperature). Although temperature can be accurately measured, film and processing quality together can only be indirectly determined from the resultant film optical densities, which addresses the entire processing system.

5.5 Densitometer

5.5.1 **Question:** Do all densitometers perform the same?

Answer: Generally yes, but they should be calibrated. Densitometers are highly precise and accurate, can be calibrated using optical film density tablets traceable to national standards, and are generally affordable.

5.6 Thermometer

5.6.1 **Question:** Are all thermometers calibrated?

Answer: No, thermometer accuracy should be validated.

5.7 Film, Chemistry, and Processor Manufacturer Recommendations

5.7.1 **Question:** The film, chemistry and processor manufacturers all provide recommendations for their products. If they differ, whose should be followed?

Answer: Film performance should always be traceable to the film manufacturer's recommended processing environment. Most film types will respond slightly differently in different chemical environments. Since chemical solutions'

compositions are proprietary, there is no simple way to predict how a film will perform in a different processing environment other than collecting empirical data and comparing the films developed in these different environments. If the film performs in an equivalent way, i.e., same resultant optical densities for given sensitometric numbers as when the film was developed according to the film manufacturer's recommended processing specifications, then the processing environment can be considered equivalent.

5.8 Special Processing

5.8.1 **Question:** Is extended cycle processing used anymore?

Answer: No, extended cycle processing is no longer considered acceptable for modern mammography films. In mammography, when extended cycle processing was introduced, it became very popular. Extended cycle processing usually involved the modification of the automatic film processor to double the film development time. There were several good reasons for the acceptance of extended cycle processing at that time.[21] These are no longer valid today. Most films today are designed for standard cycle processing. There are no mammography films on the market today designed for extended cycle processing.

Other types of specialized processing are periodically recommended for different types of film. In these situations it is critical that the film manufacturer's recommendations be followed.

APPENDIX A

A METHOD FOR EVALUATING EQUIVALENT FILM PERFORMANCE IN OTHER MANUFACTURERS' DEVELOPER AND FIXER SOLUTIONS

To determine if another manufacturer's developer and fixer are within your film manufacturer's acceptable range for their film, you will need to have access to a processor using the film manufacturer's recommended chemistry (developer, fixer, and starter solutions, as applicable).

NOTE: This procedure will take from 2 to 8 hours to perform depending on access and logistics. All steps in the procedure should be performed on the same day.

I. Materials and Equipment

1. A light sensitometer and densitometer that reads accurately from optical density of base + fog to above 4.00.
2. Calibrated Digital Thermometer. An oral, non-mercury medical thermometer provides high accuracy.
3. Stopwatch.
4. A fresh box of film.
5. Properly mixed film manufacturer's developer.
6. Manufacturer's recommendations should be followed regarding seasoning, either with exposed film or known amount of starter solution.
7. Properly mixed other manufacturer's developer solution, and other manufacturer's recommended seasoning or amount of starter solution.
8. Radiographic phantom.

II. Setup, Exposure, and Processing the Test Films

Set up the processor according to the film manufacturer's recommendations for the film being tested.

1. Fill the processor with the film manufacturer's recommended developer solution, using the appropriate amount of starter solution, and fixer. Instead of starter solution, the processor may also be seasoned by processing a certain quantity of exposed films (please follow the film manufacturer's recommendations).
2. Using the calibrated thermometer, verify that the developer temperature is set according to the film manufacturer's recommendations.
3. Set the developer and fixer replenishment rates to the film manufacturer's recommendations for processor type and film.
4. Measure the film development time (see appendix C).

5. Verify that the sensitometer settings, if they exist, are set properly (according to the manufacturer's recommendations) and recorded. For a single-emulsion film, be sure that the emulsion side faces the light-exposing source.
6. Expose three films with your sensitometer, with each film being exposed sensitometrically at least two times; once on the left side, once on the right side. Wait a consistent time between sensitometric exposures (20 seconds being a reasonably period of time), and wait a similar amount of time prior to feeding the film into the processor.
7. Process the film consistently, using either the right-hand side, the center, or the left-hand side of the feed tray.
8. Label all films. Record developer used, date, time, and any other relevant information.
9. Establish exposure techniques for an acceptable radiograph using an appropriate quality control phantom. Use the same mode and technique (mA, time, kVp, geometry) for the subsequent images. You may use manual or automatic techniques, but the technique should be reproducible for future comparisons.
10. Expose and process a set of phantom films using the above technique. Record the background densities at the same point for each image.
11. Drain the developer solution, change the developer filter, and thoroughly rinse the tank, rack, and developer-to-fixer crossover assembly. Repeat steps 1–10 using the other manufacturer's developer and fixer.

III. Evaluating the Sensitometric Films

1. Read the film optical density for each sensitometer step number using the calibrated densitometer. Plot the optical density versus the sensitometer step number for each film. Always keep the film types by specific processor environment together.

   The sensitometric step numbers corresponding to a net density of 0.25 and 2.00 are interpolated from a plot of film optical density versus sensitometer step numbers.

   Average gradient, an industry metric for contrast, is:

$$\text{Average Gradient} = \frac{1.75}{(SS_{2.00} - SS_{0.25}) \times 0.15}$$

   where

   $SS_{2.00}$ = Sensitometer step number corresponding to net density of 2.00 above base + fog,

   $SS_{0.25}$ = Sensitometer step number corresponding to net density of 0.25 above base + fog, and

   0.15 is the log rel E for consecutive step numbers for the light sensitometer used.

2. Interpolate the speed step which corresponds to the speed density, which is the sensitometer step number corresponding to the net density of 1.00, and the average gradient for the three films processed using the film manufacturer's developer and fixer solutions and processing specifications.
3. Repeat for the films processed through the other manufacturer's developer.
4. Compare the speed and average gradient for the film processed in the other manufacturer's chemistry to that processed in the film manufacturer's chemistry.

IV. Generating X-ray Phantom Film(s) for Comparison

In order to relate these processing conditions with actual radiographic quality for quality control purposes, it is important to perform baseline x-ray quality control tests at this time. These will include such tests as exposing a standard reference object, usually an imaging phantom, in a standard way, with known film and intensifying screen. The resultant film(s) then need to be evaluated in terms of critical imaging metrics.

APPENDIX B

THE SENSITOMETRIC TECHNIQUE FOR THE EVALUATION OF PROCESSING (STEP)

The Sensitometric Technique for the Evaluation of Processing (STEP) is used to measure processing speed. STEP assigns a single metric, referred to as the processing speed, a value of 100, which corresponds to the speed density, defined as the net density of 1.0 above the base + fog of the film. STEP was originally developed for use in the Nationwide Evaluation of X-ray Trends (NEXT)[22,23,24] in which variations in processing performance among a variety of diagnostic radiology facilities were identified. STEP was also employed as part of the NEXT mammography surveys and incorporated into the annual federal mammography inspection program.[25]

The purpose of STEP is to identify automatic processors that are deviating significantly from the recommendations of the film manufacturers. Although a single control film is used, the control film selected is evaluated along with all major mammography films in all major film manufacturers' recommended processing environments. This control film selected may not be the actual type of film used clinically for a given mammography facility. Prior to selection of the standard control film, most major films are evaluated in a variety of chemical solutions and processing conditions to verify that these films perform in a comparable manner. This is not practical for the individual medical physicist.

The control film selected is tested against most of the other types of films and is selected based on its representative response.

The test is conducted using a sheet of control film from the same emulsion batch that has been exposed to a sensitometer that has been calibrated with a specified control film. The resulting film optical densities are read with a densitometer, using a National Institute of Standards and Technology (NIST) traceable reference film optical density tablet. When the measured film optical densities are equivalent to the film optical densities obtained when this control film has been developed according to the film manufacturer's recommendations, a processing speed of 100 is assigned to that processor.

Due to logistics necessary to support a nationwide program, a single control film from a single emulsion batch is used to evaluate a variety of processors, some of which use film that may be different from the control test film. The test generates a metric, processing speed, which assigns a value of 100 when the film processor is performing according to the film manufacturer's recommendations. Differences of as much as 20% are tolerated, although the pooled standard deviation for the entire set of approximately 250 sensitometers and test film is approximately 4%.

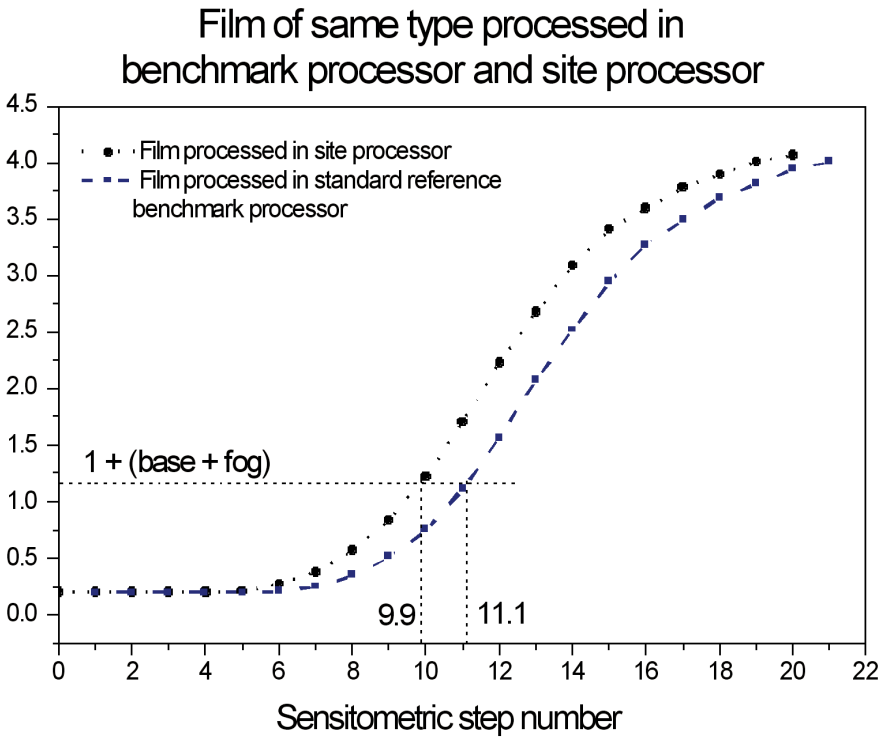

Figure B-1. Density versus Sensitometer Step Number (0.15 log rel E per step) for two different processing conditions.

Processing Speed, for a specific sensitometer, and specified control film is defined as follows:

$$\text{Processing Speed} = 10^{(S_r - S_o)\times 0.15} \times 100$$

where

S_o is the observed speed step for the processor undergoing evaluation,

S_r is the reference speed step when the film is processed according to the film manufacturer's recommendations,

0.15 is the log relative exposure difference corresponding to one sensitometer step difference, and

100 normalizes the quantity to 100 for film developed according to the film manufacturer's recommendations.

Speed step is the sensitometer step number interpolated and corresponding to the speed density.

Speed density is defined as a net density of 1.00 above the base + fog of the film.

For the two films shown in Figure B–1 the standard reference curve is the one to the right and has a speed step of 11.1. The site processor's curve is to the left, requiring less light to yield the same optical densities, since it requires less exposure; it is therefore "faster" than the standard reference curve.

Therefore $S_o = 9.9$ $S_r = 11.1$

Processing Speed $= 10^{(11.1 - 9.9) \times 0.15} \times 100$

$= 10^{(1.2) \times 0.15} \times 100$

$= 10^{0.18} \times 100 =$ **151**

In this example, the processor has a processing speed of 151, which is considered overprocessing. This is clearly outside the range of recommended performance and is indicative of a variety of possible problems. Although an overprocessing processor will usually have a lower radiation dose for a given optical density, other problems associated with image quality, such as reduced contrast and increased noise, will clearly offset this apparent benefit. The intent is to validate that the film is performing as the film manufacturer designed the film, i.e., with a processing speed of 100.

Another key concept to understand here is that processing speed is inversely related to exposure. A processor with a processing speed of 50 requires twice the radiation exposure to generate the same optical density; one with a processing speed of 80 requires a relative increase in exposure of 25% ($1.25 \times 80 = 100$), in order to "recapture" the "lost" film optical density. In addition to the loss of speed, underprocessing will usually result in lower film contrast, always an important image quality metric.

APPENDIX C

TIME IN SOLUTION TEST FOR DETERMINING FILM DEVELOPMENT TIME

The temperature of the developer solution and the length of time a film spends in the developer solution are important considerations in determining whether the film will be properly processed (optimal optical density and contrast). This time is sometimes defined slightly differently. The length of time the film spends immersed in the developer solution is known as *film immersion time, and this time corresponds to the actual time, in seconds, that the film is immersed in solution*. Although the latent image development begins when the film comes into contact with the developer solution, it does not end even after it leaves the developer solution, but only when the film enters the fixer solution. This includes a period of time, out of solution, when the film is actually crossing over from the developer to the fixer solution. This is referred to as *film development time* and is longer than *film immersion time,* usually by a few seconds corresponding to the crossover time. It is usually defined as the amount of time from the leading edge of the film into the developer solution to the leading edge of the film into the fixer solution. Either of these can be easily measured, but should be compared to what the manufacturer actually specifies, film development time, or film immersion time.

A time-in-solution (TIS) test tool should be made, consisting of a strip of clear film, which has been generated by processing an unexposed film, and two white strips of tape. Note that motor speeds will vary slightly from processor to processor of the same type; the TIS tool should be used to validate development time for the processor.

The procedure is as follows:

1. Remove the lid of the processor. Some processors require a small magnet placed near the microswitch to allow the processor to operate without the lid in place.
2. Locate the entrance detector crossover and the guide shoe. Also, locate the gap between the developer-to-fixer crossover assembly and the guide shoe.
3. Feed the test tool into the processor, placing the tool either along the left or right film feed tray guide or in the center of the film feed tray. Be consistent.
4. With a stopwatch, begin timing when the same part of the tool passes through a specified point in the entrance detector crossover.
5. Stop timing when the same part of the tool reaches a similar specified point in the developer-to-fixer crossover assembly.
6. Repeat the timing sequence three times and take an average to determine the film development time or film immersion time.

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