Light sensitometry of mammography films at varying development temperatures and times

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Received on: 25.05.11 Review completed on: 05.06.11 Accepted on: 03.11.11

ABSTRACT
Kodak MinR-2000 mammography film is widely used for mammography imaging. The sensitometric indices like base plus fog level (B + F), maximum optical density (OD$_{\text{max}}$), average gradient (AG) and speed of this film at varying development temperatures and times were evaluated using a light sensitometer. Totally 33 film strips were cut from a single Kodak MinR-2000 mammography film box and exposed in a light sensitometer operated in the green light spectrum to produce a 21-step sensitometric strip. These exposed film strips were processed at temperatures in the range of 32°C–37°C in the step of 1°C and at processing times in the range of 1–6 minutes in the step of 1 minute. The results of the present study show that the measured base plus fog level of the mammography film was not affected much, whereas significant changes were seen in the OD$_{\text{max}}$, AG and speed with varying development temperatures and times. The OD$_{\text{max}}$ values of the film were found in the range of 3.67–3.76, AG values were in the range of 2.48–3.4 and speed values were in the range of 0.015–0.023 when the processing temperature was varied from 32°C to 37°C. With processing time variation from 1 to 6 minutes, the observed changes in OD$_{\text{max}}$ values were in the range of 3.54–3.71, changes in AG were in the range of 2.66–3.27 and changes in speed were in the range of 0.011–0.025. Based on these observations, recommendations for optimum processing parameters to be used for this film are made.

Key words: Average gradient, base plus fog, mammography, optical density, speed, sensitometry

Introduction
Mammography is the single most important tool in the early detection of breast cancer.[1] The quality of the mammographic image depends upon the equipment and processing methods used for the films.[2] Light sensitometry is a suitable method to measure the performance of the processor and evaluation of the film performance.[3,4] Mammography technique requires high radiographic contrast that is influenced by subject contrast and film contrast. Film contrast depends upon the film type, film processor, processor chemicals/processing cycles and fog. Different mammographic films present different sensitometric characteristics which can be altered by the processing conditions.[3,5] Thus, in a mammography facility, any change in film type, film processor, processor chemicals or processing cycles should be thoroughly investigated using standard techniques before mammograms of patients are acquired.[6]

In mammography imaging, the film processor has been identified as the weakest link for production of the poor image quality. Several studies in this direction have reported that major cause for low contrast and high dose values observed in the mammography is poor film processing conditions.[7] The American College of Radiology (ACR, 1999) manual describes comprehensive procedure for processor quality control (QC) including processor operating levels, daily sensitometry and film crossover effects.[8] Also, according to the ACR mammography QC protocol, it has been recommended that for mammography film processing, a dedicated processor unit should always be maintained as typical single-sided emulsion-coated mammography films, being slow-speed films, require more developing time for proper development.[8]

In India, many of the mammography centers use either Kodak or Agfa mammography films, but Kodak is the film...
which is used in large quantity. The information related to processor type, processing temperature/time, chemicals, film and pH of the processing solutions was collected by on-site visit to 30 mammography centers in Mumbai, India. From the survey results, wide variations in these parameters have been observed which are shown in [Table 1]. The present study investigates the effect of variability of these parameters, mainly changing the development temperature and time on the sensitometric indices like base plus fog, maximum optical density \( (OD_{\text{max}}) \), average gradient (AG) and speed of Kodak MinR-2000 mammography film. The aim of the study was to emphasize the importance of dark room QC procedures to be carried out by the technologists in the mammography centers of India as it is well established that daily QC program for the processing conditions will remove any discrepancy incurring due to processor related variables which may spoil the patient’s film images, leading to retake.

**Materials and Methods**

**Light sensitometry**

Totally 33 film strips were cut from a single Kodak MinR-2000 mammography film box. Assuming film to film variation is negligible, these film strips were randomly grouped together to form three sets comprising 11 film strips per set. A Victoreen dual color and dual control electronic sensitometer model 07-417 operated in the green spectrum was used to produce a 21-step sensitometric strip. Every subsequent step transmitted 40% more light than the previous step and was associated with an increase of a log relative exposure of 0.30.

**Processing**

A set of three film strips was exposed using a light sensitometer for a given processing temperature and time. To examine the effect of varying development temperatures on the film sensitometric characteristics, these strips were developed in an automatic film processor [PROMAX™, Chayagraphics (India) Pvt. Ltd., Bangalore, India] with Rolex processing chemicals, which has an outer knob for temperature control. The processor model has a constant development time of 1.5 minutes. As the variation of development time was not possible in this automatic processor, a manual processing facility with Kodak chemical was employed to study the effect of varying development times on the film sensitometric characteristics at a constant development temperature of 26°C ± 1°C. The manual processing facility comprises three anti-corrosion steel tanks, each of 30 liters capacity, which were separately mounted on the stands made up of iron rods. A digital thermometer having the range of −1.0 to 19 pH, resolution of 0.1°C, and ±0.2°C accuracy was used to measure the temperature of developer, water and fixer solutions. A pH meter having the range of −1.0 to 19 pH, resolution of 0.1 pH and accuracy of ±0.1 pH was used to verify the pH of the developer, water and fixer solutions.

### Table 1: Summary of the survey conducted at 30 mammography centres in Mumbai, India, to acquire information related to mammography processing conditions

| Processor      | Number of processor units | Temperature control option | Measured temperature ranges | Processing time (seconds) | Chemicals used                                                                 | Film used | Measured pH ranges of developer/water/fixer |
|----------------|----------------------------|-----------------------------|----------------------------|--------------------------|--------------------------------------------------------------------------------|----------|-------------------------------------------|
| Kodak M 35 XO-Mat | 8                         | Inside                      | 28°C–30°C                  | 90                       | Kodak medical X-ray chemicals, Agfa medical X-ray chemicals, Fuji medical X-ray chemicals | Kodak, Agfa | 9.2–10.6/7.0–7.1/4.0–5.8                |
| Protec Optimax | 7                         | Outside                     | 30°C–33°C                  | 90                       | Kodak medical X-ray chemicals, Agfa medical X-ray chemicals, Fuji medical X-ray chemicals, Rolex processing chemicals | Kodak, Agfa | 8.5–10.1/6.9–7.0/3.6–4.9                |
| Konica SRX-101A | 2                         | Outside                     | 29°C–33°C                  | 90                       | Kodak medical X-ray chemicals, Agfa medical X-ray chemicals, Fuji medical X-ray chemicals, Konica medical X-ray chemicals, Rolex processing chemicals | Kodak, Agfa | 9.5–10.5/7.0–7.5/4.8–5.2                |
| Promax         | 6                         | Outside                     | 29.5°C–33°C                | 90                       | Kodak medical X-ray chemicals, Agfa medical X-ray chemicals, Fuji medical X-ray chemicals, Rolex processing chemicals | Kodak, Agfa | 9.0–10.7/6.9–7.2/5.0–5.3                |
| Velopex ExtraX | 3                         | Inside                      | 32.5°C–34°C                | 90                       | Kodak medical X-ray chemicals, Agfa medical X-ray chemicals, Fuji medical X-ray chemicals, Rolex processing chemicals | Kodak, Agfa | 8.9–10.3/7.1–7.2/3.9–4.8                |
| Ecomax         | 1                         | Outside                     | 30°C–30.5°C                | 117                      | Kodak medical X-ray chemicals, Agfa medical X-ray chemicals, Fuji medical X-ray chemicals | Kodak, Agfa | 9.0–10.5/7.0–7.6/3.8–5.5                |
| Manual         | 3                         | Outside                     | 26°C–28.1°C                | Variable as per the technologist’s choice | Premier X-ray chemicals, India, photon X-ray processing chemicals, Agfa medical X-ray chemicals | Kodak, Agfa | 9.1–11.8/7.0–7.3/2.7–5.9                |
Densitometry

The OD is defined as the logarithmic ratio of the incident light intensity to the transmitted light intensity. For measurements of the OD of the film strips, a standard diffuse transmission Optel Trans-4 densitometer having white light source and an accuracy of \( \Delta D = \pm 0.01 \) was used. To study the sensitometric indices of a mammography film, Hurter and Driffield (HandD) curves were plotted for three film strips corresponding to one set of processing conditions. This densitometer was calibrated to photographic density strip standards traceable to NIST, USA.

Evaluation of sensitometric parameters

Characteristic curves were measured for five different development temperatures and six different development times. The base plus fog level, \( OD_{max} \), AG and speed were calculated from the characteristic curve of each film strip. For a single set of processing conditions, three film strips were analyzed as we have processed the three film strips in a single processing condition. The mean values and standard deviations of these three film strips data were calculated.

A base plus fog level of more than 0.20 OD is generally recommended as unacceptable.\cite{9} Therefore, measurement of this parameter is most important. The base fog density is defined as the OD of an unexposed film simply after fixing the film, whereas the base plus fog density is referred to as the density of unexposed film when it is subjected to the complete film processing cycle. The AG of the characteristic curve is an indication of the contrast of the film. The AG is determined by the slope between the two points with an OD of 0.25 + base plus fog and an OD of 2.0 + base plus fog. The required AG for a mammography film is \( \geq 3.0 \). Speed is used to evaluate the film sensitivity. Speed is defined as the inverse of the log relative exposure required to achieve an OD of 1.0 + base plus fog. The maximum OD which can be produced on a film is called its OD\(_{max}\) and its specified limit for a mammography film is \( \geq 3.0 \) OD.

Results and Discussion

Figure 1 shows the characteristic curves of a Kodak MinR-2000 mammography film at five different development temperatures (32°C, 33°C, 34°C, 35°C and 37°C) and a constant development time of 1.5 minutes. Figures 2a–2c show the measured variation in the AG, speed and \( OD_{max} \) of the film at five different development temperatures, respectively. Figure 3 shows the characteristic curves of a single emulsion Kodak MinR-2000 mammography film at six development times (1, 2, 3, 4, 5 and 6 minutes) and a constant development temperature of 26°C ± 1°C. Figures 4a–4c show the measured variation in the AG, speed and \( OD_{max} \) of the film at six development times, respectively.

Base plus fog level

The base plus fog levels of the film strips were not adversely affected with change in development temperatures and times involved in the study. Although not shown, the constant base plus fog level of 0.11 ± 0.00...
was recorded when the development temperature was varied from 32°C to 37°C. For the development times between 1 and 4 minutes, the base plus fog level was 0.11 ± 0.00 and for the development times between 5 and 6 minutes, the base plus fog level had a single value of 0.14 ± 0.00.

**Film contrast**

The AG for the developing temperatures and times is presented in Figures 2a and 4a, respectively. When the developing temperature was increased from 32°C to 34°C, the average film gradient decreased from 3.29 ± 0.01 to 3.13 ± 0.005, respectively, at a fixed development time of 1.5 minutes. There was a rapid increase in average film gradient from 3.13 ± 0.005 to 3.4 ± 0.00 when the developing temperature was increased from 34°C to 35°C, which means an increase in contrast level of 23%. When the developing temperature was increased from 35°C to 37°C, there was a rapid decrease in the AG of the film from 3.4 ± 0.00 to 2.48 ± 0.01, which means a decrease in contrast level of 37%.

The average film gradient increased from 3.05 ± 0.005 to
3.27 ± 0.01 when the developing times were increased from 1 to 3 minutes at a fixed development temperature of 26°C ± 1°C. The AG started decreasing from 3.27 ± 0.01 to 2.66 ± 0.02 when the times were increased from 3 to 6 minutes.

**Speed**

The values of speed for the different temperatures and times are shown in Figures 2b and 4b, respectively. A rise in temperatures from 32°C to 37°C had an appreciable impact on the speed of a film which increased from 0.015 ± 0.000 at 32°C to a maximum value of 0.0236 ± 0.000 at 37°C, which means a decreased radiation level of 56%.

At a fixed development temperature of 26°C ± 1°C, the speed increased when the developing times were increased from 0.011 ± 0.000 at 1 minute to a maximum value of 0.025 ± 0.000 at 5 minutes, which means a decreased radiation level of 25%. At a development time of 6 minutes, the speed of the film was measured as 0.017 ± 0.000, which means an increased radiation level of 48% when compared with maximum speed obtained at 5 minutes development time.

**Maximum optical density (OD$_{\text{max}}$)**

The OD$_{\text{max}}$ values produced on a film for the different temperatures and times are shown in Figures 2c and 4c, respectively. A rise in temperature from 32°C to 37°C shows the increase in OD$_{\text{max}}$ of a film from 3.74 ± 0.01 at 32°C to a maximum value of 3.76 ± 0.05 at 34°C. When the development temperature was increased from 34°C to 37°C, the OD$_{\text{max}}$ decreased from 3.76 ± 0.05 to 3.67 ± 0.02 as shown in Figure 2c.

At a fixed development temperature of 26°C ± 1°C, a rise in development time from 1 to 6 minutes had an appreciable impact on the OD$_{\text{max}}$ of a film as it was increased from 3.54 ± 0.03 at 1 minute to a maximum value of 3.71 ± 0.01 at 4 minutes. When the development time was increased from 4 to 6 minutes, the OD$_{\text{max}}$ decreased from 3.71 ± 0.01 to 3.61 ± 0.05. The observed OD$_{\text{max}}$ values did not show much significant change with the applied processing variables.

Alteration in the sensitometric indices, for example, AG, film speed and OD$_{\text{max}}$ of a mammography film, due to influence of development temperature and time can be seen in the present study. In this context, it may be noted that Tsalafoutas et al. [10] had made an investigation to study the variation of the seven mammography films with processing conditions and showed that the different mammography films presented different sensitometric characteristics that could be altered by the processing conditions.

It is evident from the present study that for the investigated film and the processing variables, the best development temperature range is 32°C–35°C for an automatic processor cycle time of ~1.5 minutes, as on these settings the AG requirement needed for a film has been optimized. In case of required film speed and OD$_{\text{max}}$ values, the above-said temperature settings are again considered to be the best choices. Also, it can be seen from Figures 4a–c that the best suitable development time range for the manual processor setting applied in the study is 3–5 minutes for getting the optimized parameters investigated, for example, AG, film speed and OD$_{\text{max}}$.

**Conclusion**

Sensitometric characteristics of the Kodak MinR-2000 mammography film were evaluated with varying processing temperatures and times as in most of the surveyed centers it was observed that the measured and set temperature on the processor varied by more than 5°C. Even the temperature control system of the processors was not working in many of the facilities. It was also observed that at some of the places, manual processors were in use which had contributed large variation in the development time of mammography film. It was also observed that replenishment rate of the developer solutions was inadequate which resulted in a rapid decrease in the concentration of the developer solution. The use of a common processor for processing the radiography films (X-ray radiography and mammography) of radiology department was found to be the major reason for the inadequate replenishment. Also, at a few centers, it was observed that the pre-used and exhausted developer solution was sent back to the machine as replenishment. This mammography film is widely used in most of the mammography departments and shows the influence of processing conditions on its sensitometric characteristics. Although a single type of mammography film was used in this study, the effect of processing variables on any type of mammography film cannot be excluded, which brought the changes in its sensitometric indices due to varying processing conditions.

In-depth analysis of sensitometric characteristics of a film from the contrast and radiation level point of view shows that there is a need for each mammography center to carry out sensitometric study for their film and development chemistry to optimize the image quality and radiation dose levels. Further, in India, where the workload for routine radiography is much significant in comparison to mammography workload, it becomes impractical to have a dedicated mammography processor. With the use of a common processor, it becomes utmost important that the processor undergoes daily QC check and a record for the same is maintained and analyzed because the use of a common processor results in rapid decrease in the concentration of the developer solution if the replenishment rate is inadequate. It was also observed that none of the facilities were having processor QC equipments like densitometer, densitometer, pH meter and digital thermometer. While interacting with the mammography technologists working
in these centers, it was found that majority of them were not aware about the mammography QC procedures. Considering the importance of mammography QC program for dark room procedures, it is advisable that the frequency-based QC program should be initiated at a national level in every mammography center involving mammography technologists.

Acknowledgments

Authors wish to express their gratitude to Dr. A. K. Ghosh, Director, Health, Safety and Environment Group (HS and EG); Dr. D. N. Sharma, Associate Director, HS and EG, Dr. G. Chaurasia, Head, Medical Physics and Training Section, RPAD, Bhabha Atomic Research Centre, Mumbai, for their encouragement and support. Authors also express their sincere gratitude to the staff of mammography centers for their help in measurements.

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How to cite this article: Sharma R, Sharma SD, Mayya YS. Light sensitometry of mammography films at varying development temperatures and times. J Med Phys 2012;37:40-5.

Source of Support: Nil, Conflict of Interest: None declared.