Xerography of the Breast[1]

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XEROGRAMS of the breast have the following advantages over film mammograms: (*a*) they are easier to interpret; (*b*) they require less radiation to produce than Eastman Kodak "M" film mammograms; (*c*) they afford greater detail; (*d*) they are probably more accurate; (*e*) xerography is a dry process; (*f*) the finished product is obtained more quickly and with greater ease.

The most important feature is that they are easier to interpret. Properly set-up xerograms could probably be read in a screening program at the rate of 4–5 cases per minute, whereas in a similar program film mammograms were read at a rate of 15–20 cases per hour (16).

An additional advantage of xerography is that all parts of the breast are clearly shown with one image. Some workers in mammography believe that two x-ray films of different densities are required to delineate all structures (17, 18). It is my opinion that xerograms are more accurate, although I have not conducted a carefully controlled study to prove this (10, 13).

The essential part of xerography is the "plate," which consists of a sheet of aluminum, 10 × 17 inches, coated with a thin layer of selenium and encased in a wooden "cassette," complete with a dark slide to protect it from light. The plate is used as one would an x-ray film insofar as performance of the examination is concerned.

REVIEW OF THE LITERATURE

Investigators at St. Vincents Hospital, New York City, have published three papers on xerography of the breast (4, 10, 13). The first was a description of the early experience with a small number of patients. The second paper was more complete and explained in detail the xerographic principle and the equipment available. The technic was discussed, together with some shortcomings that had become apparent. The last paper from this group summarized the experience gained from 463 breast examinations. When results were compared, xerography and roentgenography were exactly the same in accuracy of diagnosis of malignant disease.

Other papers on xeroradiography, describing its use in aspects of radiology other than mammography, include two by Roach and Hilleboe. Their first article, which was of an introductory nature, explored the use of the procedure in the event of an emergency created by the explosion of an atomic bomb. They also discussed the physical aspects of the procedure and the results of early clinical testing (11). Their second article called attention to the relatively slow "speed" of xeroradiography in comparison with conventional roentgenography performed with "fast" film and intensifying screens (12).

Hills *et al.* (6) noted the slow speed and low contrast of xeroradiography but also cited the great detail possible with preservation of all structures of varying densities. Oliphant (9) described briefly the apparatus and method of use and noted the great detail attainable. Farmer *et al.* (3) utilized the process in radiation-treatment planning and cited its advantages in recording all tissue densities.

There are numerous articles on xerography and xeroradiography in nonradiological literature. McMaster (7) has written a very readable account on all technical aspects; included is a historical review of the basic principle, its discovery and patent by Charles F. Carlson in 1937, and its subsequent development by the Battelle Corporation.

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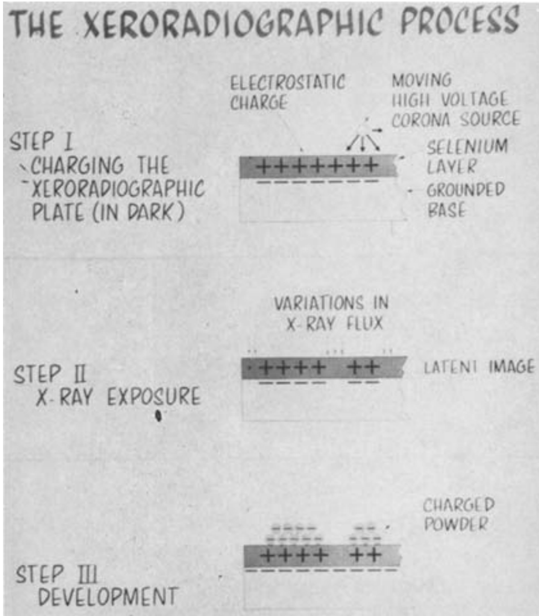


Fig. 1. Xerography is possible because selenium is a photoconductor. An electrostatic charge placed on its surface will remain in an absence of radiant energy. X rays make the selenium conductive perpendicularly. After exposure there is a residual charge pattern which may be made visible by "developing" with a negatively charged, pigment-containing powder.

TECHNICAL CONSIDERATIONS

Technical considerations that concern the radiologist are speed, contrast, and artefacts, which are interrelated, and dark decay.

The speed of the plate is a function of the number of carriers created within the selenium during exposure to x rays. This is proportional to the number of atoms of selenium present for interaction with the x rays (selenium thickness) and also to how close the radiant energy is to 12–13 kilovolts, which is the amount of force required to remove an electron from the k shell of the selenium. X rays significantly higher than 12–13 kilovolts are likely to pass through the plate without interaction. Very thin layers of selenium will be significantly slower than thick ones, as x rays will be more likely to escape through the photo-conductive layer without interaction.

We note an increase in speed and contrast in the following situations: (*a*) a thick selenium layer, as opposed to a thin one; (*b*) replacement of the aluminum dark slide of the cassettes (1/35 inch) with one made of plastic (1/16 inch); (*c*) reduction to 30–32 kV with 900 mAs, as compared to 40–42 and 150 mAs. These factors affect contrast in that background color is diminished by more complete loss of the initial plate charge in the areas of exposure where there is no breast.

Contrast is also related to initial plate voltage and the amount of exposure. The higher the initial voltage, the greater the contrast. Too high plate voltage will result in 0.1 to 0.5-mm areas where no powder is deposited (powder deficient spots). These are unimportant outside the image area; their presence to a severe degree in it can destroy the xerogram's value.

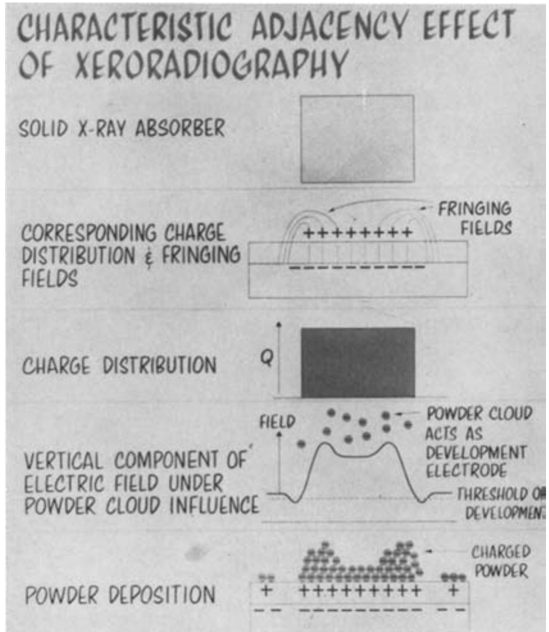


Fig. 2. Fringing electric fields around differences in potential effectively increase the charge. A heavier deposition of powder occurs at the edges of masses.

Overdevelopment with the blue plastic powder will diminish contrast. The optimum is just enough developer to record all areas of interest with minimum background. There is competition between breast structures and background for the developing powder, and the stronger fields depicting dense structures are developed first, to a degree. Slow development—small amounts of powder over long periods of time (fifty seconds)—appears better than fast development with large amounts of powder and ten to fifteen seconds.

DARK DECAY

Dark decay is an exponential loss of plate charge. This is due in part to cosmic radiations, free ions in the air, and the fact that selenium is not perfect in its resistivity. The decay is slight but is most marked immediately after plate charging. One cannot delay unnecessarily between plate charging, exposure, and development. These need not take more than three to four minutes at most.

EQUIPMENT

The equipment has been described by Ruzicka *et al.* (13). It was built in 1955 for field trial. The construction is such that there can be no large-scale use of this technic until more reliable and semiautomated machines are available. A design requiring only 2 or 3 manual steps and a finished product available in a minute or so is practicable.

TECHNIC

From the foregoing discussion, it is obvious that the best xerograms are obtained with low kilovoltage, high mAs, and slow developing. The beam should not be filtered any more than is unavoidable, either before or after striking the breast. A slice of breast tissue imbedded in plastic in which were placed small flakes of aluminum hydroxide (prepared by Dr. Robert Egan) was examined in studies with various factors. There is no significant loss in detail as one goes from 900 to 300 mAs (Fig. 3).

Twenty-four to thirty-two kilovolts and 600 mAs at 32 inches produce an image of good quality. These factors will vary according to the character of the selenium plates made available in the future.

TECHNICAL DIFFICULTIES

Damage to the xerographic plates during handling is likely to occur with present technics because the plates have to be manipulated a considerable number of times during processing. The surface of the selenium is readily scratched, which will leave a permanent artefact. Semi-automated equipment would alleviate this problem by permitting the plate surface never to be exposed.

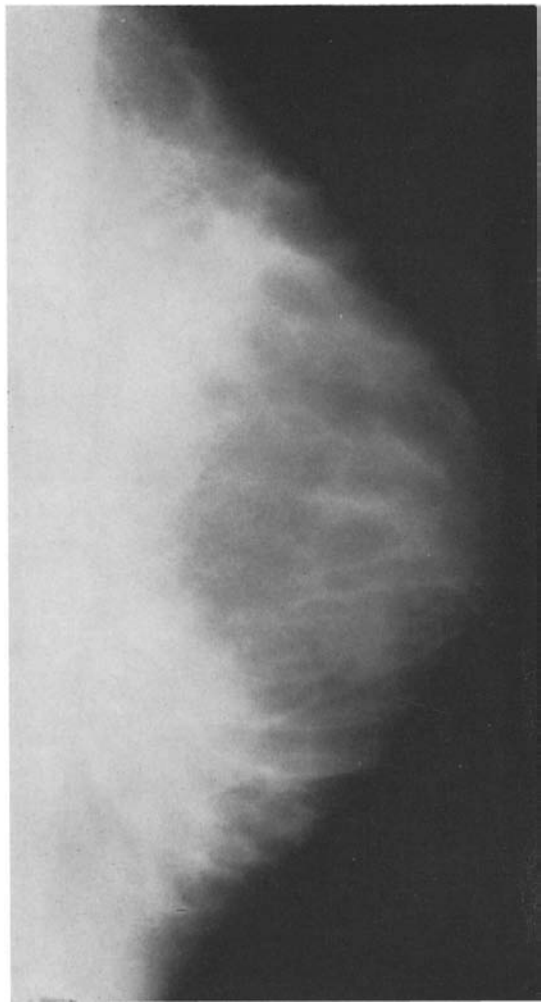


Fig. 4. Slight mammary dysplasia in 25-year-old woman.

Humidity and subsequent clumping of the developing powder was a problem early in the investigation. This was solved by discontinuing the use of the air compressor furnished with the equipment for driving the powder and substituting a tank of dry nitrogen with a reducing valve and operating it at 50 p.s.i.

Leaks around the orifice of the developing unit in which the xerographic plate rests produced a deposition of clumps of powder around the periphery of the plate. These are troublesome but, because of their

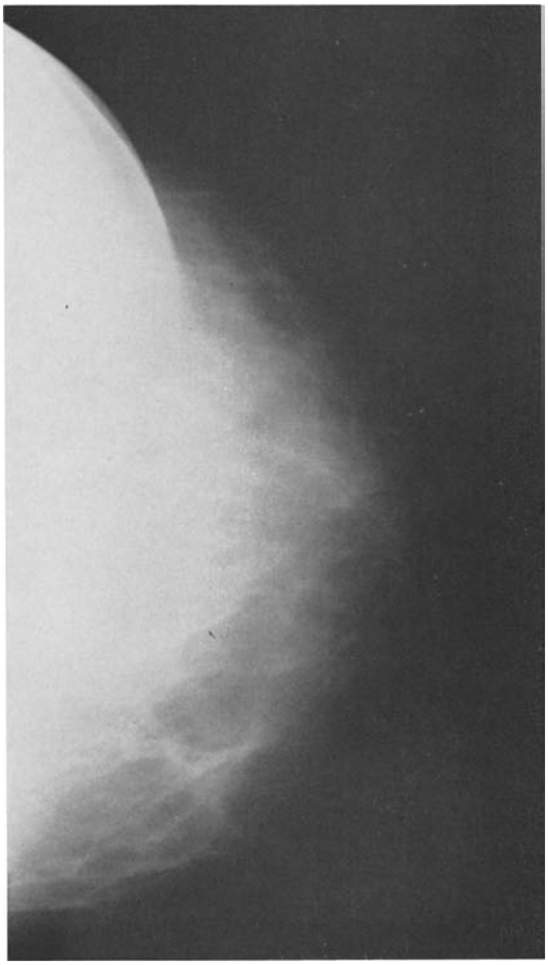


Fig. 5. B. *For legend please see Fig. 5, A, on opposite page.*

distribution and large number, are not mistaken for calcifications.

A loss of contrast occurs if the developing unit accumulates a considerable amount of used developing powder, and it must be cleaned after about ten hours of operation. The powder is reusable.

Artefacts on the images occur if the cover used to protect the plate from light

Fig. 6. B. *For legend please see Fig. 6, A, on opposite page.*

Fig. 5. D. *For legend please see Fig. 5, C, on opposite page.*

is sufficiently indented to touch the selenium surface after it is charged. This immediately discharges that area, and no powder will be attracted to it.

Difficulties have been encountered with the relaxing unit with the appearance of "ghosts" on the plates during subsequent examinations. Slight motion has occurred in the transfer unit during passage of the plate and paper through it, producing a blurring of the image. Wires have been broken by insertion of plates into the charging unit due to excessive canting of the plate. Uneven heat distribution in the fusing unit that is used to fix the powder image onto the plastic-coated paper has resulted in an uneven fusion. A change in plastic-coated paper at one time resulted in a supply that was too tacky, would not fuse properly, and gave poor images. It is apparent from the foregoing that major

Fig. 6. D. *For legend please see Fig. 6, C, on page 237.*

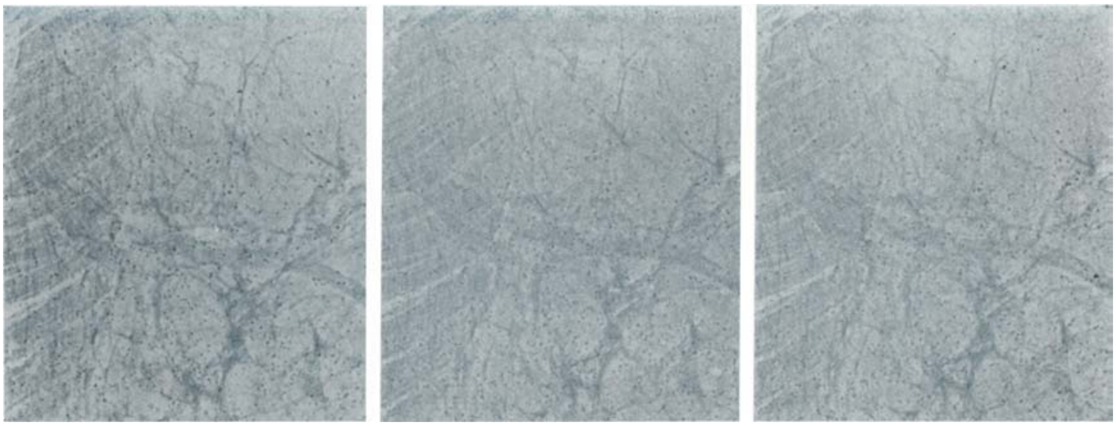
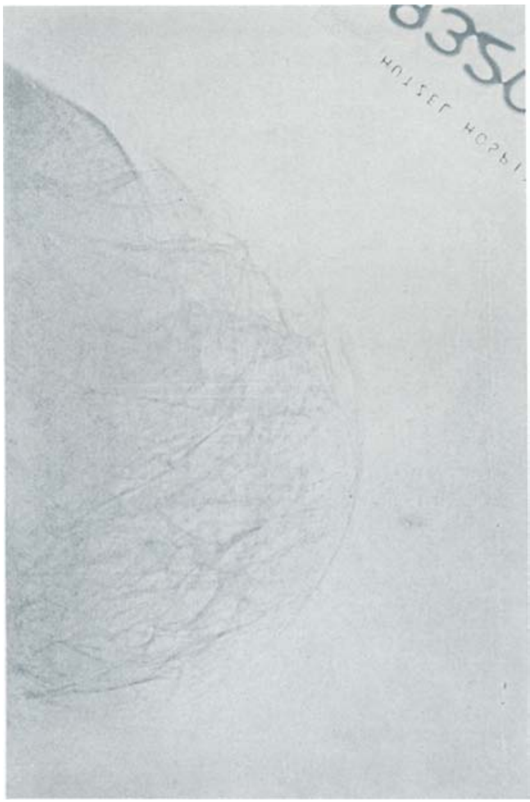


Fig. 3. Effect of mAs on contrast. A. 900 mAs. B. 600 mAs. C. 300 mAs.



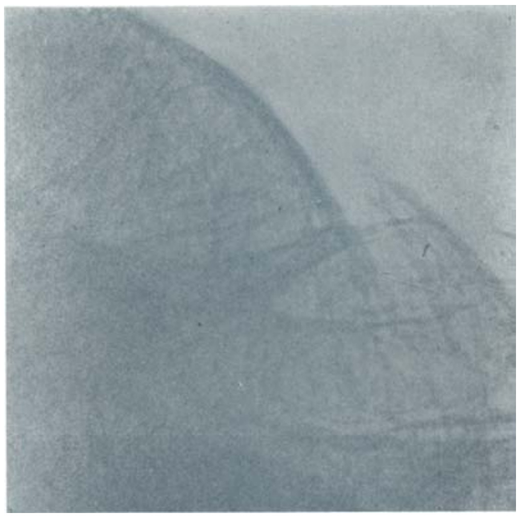


Fig. 5. A (*left*) and C (*above*). Scirrhous carcinoma. Note detail of retractions about the cancer obtainable by xerography over and above that recorded on the conventional film mammogram.

Fig. 6. A (*below*). Comedo carcinoma occupying about one half of the breast. The general architecture is depicted well on the xerogram.

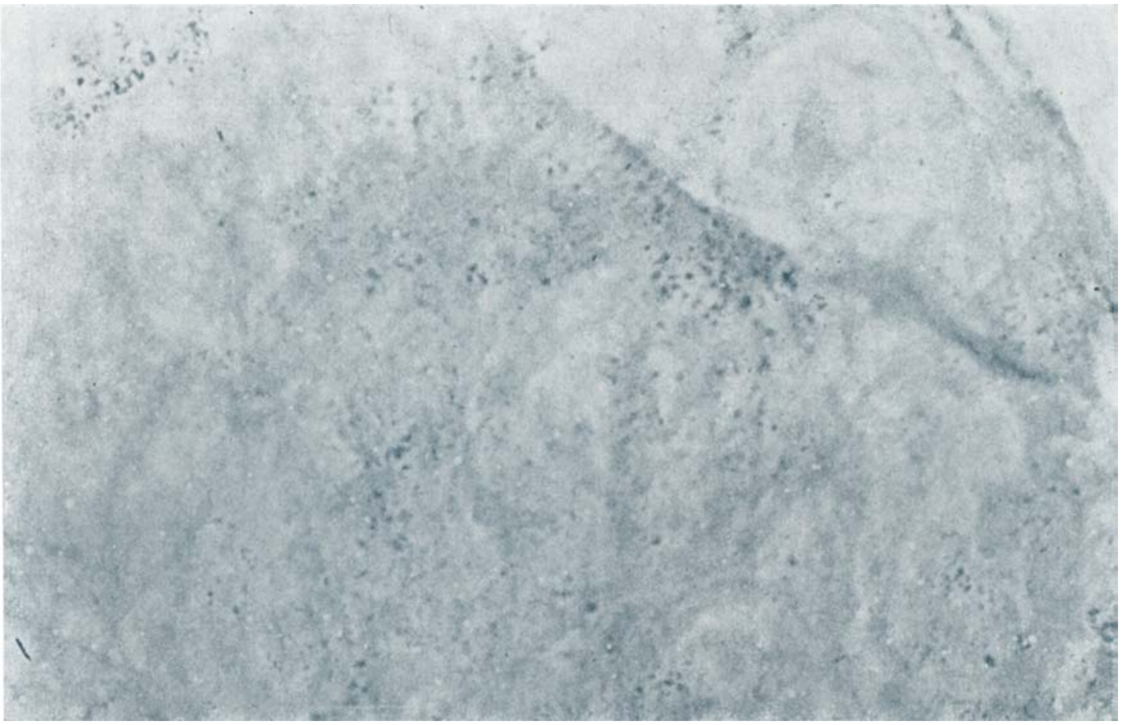


Fig. 6. C. Area of the cancer magnified (2×), illustrating the superior ability of xeroradiography to demonstrate tumor calcifications.

Fig. 7. A. Circumscribed carcinoma, small mass more readily identified on xerogram.

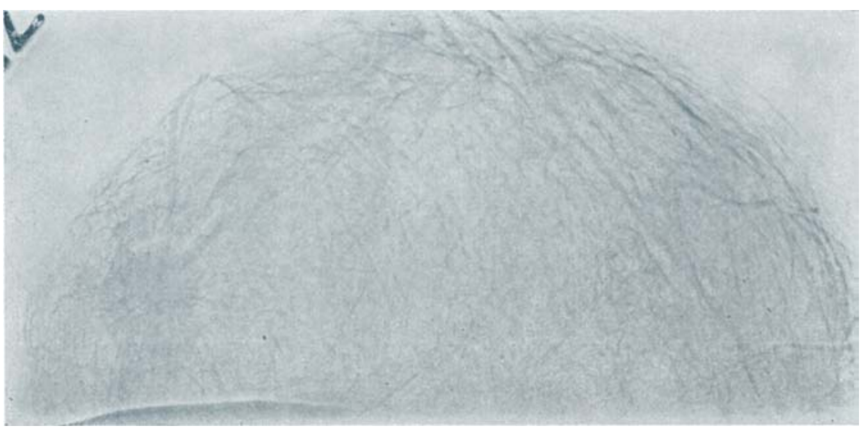


Fig. 8. A. Scirrhous carcinoma very evident on both examinations.

difficulties have been encountered with nearly every component of the equipment. Many were solved by experience. The main ones were overcome by the cooperation of the Xerox Corporation in refitting and bringing into good operating order the various components.

EXAMPLES

Examples are shown to illustrate all of the features of xeroradiography. The cases are selected to include both benign and malignant disease; the three commonly encountered forms of the latter—comedo, scirrhous, and circumscribed—are shown. Film mammograms for comparison were made *simultaneously* on Eastman Kodak "M" film by placing it on top of the xerographic cassette. The technic in the case presentations was 30–32 kV and 1200 mAs and 32 inches. The xerograms are not considered optimum, as all were made with an aluminum dark slide and many with thin selenium plates (Figs. 4–8).

DISCUSSION

A comparison between this evaluation and that of the workers at St. Vincents Hospital is interesting to detail because of certain basic differences in approach (TABLE I). The changes were made because the physical properties of selenium make it more sensitive to low kilovoltages.

A comparison of xerograms and Eastman Kodak "M" film mammograms, also of interest, is made in TABLE II.

TABLE I: COMPARISON OF TWO XEROGRAPHIC TECHNICS

	St. Vincents Hospital	Hutzel Hospital
Kilovolts	Medium	Low
mAs	Low	Medium
Latitude of exposure	Wide	Narrow
Contrast	Low	Medium to high
Technical difficulties	Many, all aspects	Many, all aspects

TABLE II: COMPARISON OF XEROGRAMS TO EASTMAN KODAK "M" FILM MAMMOGRAMS

Speed	Faster than "M"
mAs required for good image	Less than "M"
Latitude of exposure	Narrow, but greater than "M"
Contrast	High, but less than "M"

Fig. 7. B. *For legend please see Fig. 7, A, on page 237.*

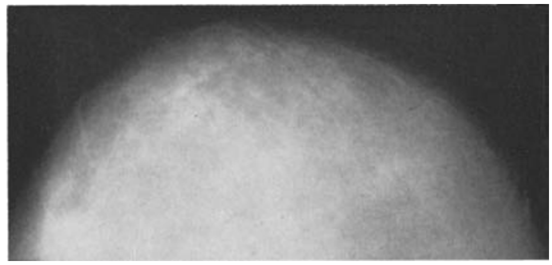


Fig. 8. B. *For legend please see Fig. 8, A, on page 237.*

CONCLUSION

Xerography is a simpler method of examination of the breast than that done with conventional x-ray film. It is my belief that more information can be obtained from a single xerogram than from any single film mammogram. With good technic, xerography will afford a more accurate examination, but, most importantly, it is more readily interpreted. The development awaits reliable equipment.

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The cost of producing the xerograms in color was assumed by the Xerox Corporation. Figures 1 and 2 were furnished by Xerox Corporation.

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