200 kV xeroradiography in occupational exposure to silica and asbestos

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ABSTRACT Some details of the physics of xeroradiography, and the bearing these have on films of the lung obtained by this technique, are discussed. In experiments designed to obtain useful films with a minimum of radiation exposure it was found that an exposure range of 10-30 mas at 200 kV at 1.35 m (4½ ft) without a grid or air gap gave very satisfactory results. The positive mode of development was considered to give more information than the negative mode. One hundred and fourteen miners who had been exposed to silica dust, asbestos dust or both, were examined by this technique. The xeroradiographs were compared with silver halide films taken at 200 kV. The xeroradiographs were considered to be superior in several respects, especially in the delineation of vascular shadows, normal and abnormal linear opacities. Linear opacities in asbestos-exposed subjects were better shown on the xeroradiographs and were occasionally seen on these films when the 200 kV conventional film was entirely normal. Small rounded opacities of silicosis were very poorly shown on the xeroradiographs. Pleural thickening and pleural plaques may be very well demonstrated.

Xeroradiography is an electrostatic method of x-ray imaging. It depends on the formation of an electrostatic image on a charged selenium layer bonded to an aluminium plate. The x-ray image is formed by altering the conductivity of those portions of the selenium layer exposed to x-rays, allowing leakage of the electrostatic charge to the aluminium base plate in proportion to the amount of radiation received. This latent image is then developed by exposure to a cloud of toner powder which is charged either negatively or positively and which attaches itself to the selenium plate according to which portions are charged and which portions are discharged. The image so formed can be made permanent by transfer to a special paper (34 cm by 22 cm) as in the Xerox 125 system.

Xeroradiography has several advantages. Edge enhancement occurs with structures which have well defined margins, emphasising the border characteristics between these structures and those immediately adjacent. Edge enhancement is attributable to a physical phenomenon whereby the vertical com-

ponent of the electric field increases abruptly at the site of a boundary between different charges, areas where the x-ray density of an image changes suddenly. This results in direction of more charged toner powder to the high-charge edge of a step and less toner to the low-charge side, producing the edge effect. As a result, boundaries are seen with much greater sharpness than in a conventional radiograph (Wolfe, 1973; Boag, 1973).

Xeroradiographs have a much wider range of latitude than conventional silver halide radiographs, so that simultaneous satisfactory recordings of structures which have markedly different radiation absorption coefficients can be made. This latitude is particularly marked with exposure at high kilovoltages and low exposure currents.

Sensitivity to low energy scattered radiation is much less than with conventional x-ray film and many techniques are possible without the use of scatter-dissipating grids or air gaps which would be necessary with conventional x-ray film-screen combinations.

Very fine resolution is possible with xeroradiography: 600 lines per millimeter can be recorded. Experimentally, resolution of 2000 lines per millimetre has been recorded with electrostatic imaging (Boag, 1973).

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Fig. 1a 200 kV silver halide radiograph.

Fig. 1b Xeroradiograph.
*Linear shadows far better
seen on latter.*

A major disadvantage of xeroradiography is the low sensitivity to radiation compared with conventional x-ray techniques. Although it is faster than industrial non-screen film, xeroradiographic film requires very much more exposure than that given by conventional fluorescent-screen x-ray film techniques, and this has largely limited more widespread use of the method. However, with higher kilovoltages and x-ray beam filtration the patient will receive lower radiation dosages than with low kV xeroradiographic techniques.

Although xeroradiography enables a wide range of densities to be seen on a single image, differences in density over broad areas with slight gradations are better seen on conventional radiographs with their greater contrasts.

The major use of xeroradiography has been in mammography (Wolfe *et al.*, 1972; Ackerman and Gose, 1973), but it has also been used in skeletal radiography (Mantel *et al.*, 1974; Wolfe, 1967), radiography of the larynx (Doust and Ting, 1974), mediasti-

num and bronchi (Chuang *et al.*, 1974; Doust *et al.*, 1974), both with and without tomography, infusion angiography (Parsavand, 1974), in some applications of neuroradiology (Baker *et al.*, 1975) and in the laboratory investigation of excised kidneys (Kapdi *et al.*, 1974) and inflated lungs (Bedrossian and Martin, 1973).

Recently von Schertel *et al.* (1975) discussed the use of xeroradiography of the chest in over 150 patients, using a 120 kV radiographic technique. Rabkin *et al.* (1971) had previously used 70-100 kV at 100-200 mas with an exposure time of 0.05-0.2 seconds without a screen grid.

Our experience

For the past three years we have been using 200 kV techniques for chest radiography at the Medical Bureau for Occupational Diseases, Johannesburg, with conventional silver halide radiographs and a high ratio reciprocating Potter Bucky grid

Fig. 2a

Fig. 2a 200 kV silver halide radiograph.

Fig. 2b

Fig. 2b Xeroradiograph, demonstrating fine linear shadows not seen in 2a. The lesser fissure and the fractured rib are more strikingly shown.

Fig. 3a

Fig. 3a 200 kV silver halide radiograph.

Fig. 3b

Fig. 3b Xeroradiograph. Linear shadows better shown than in 3a. Calcified plaques better delineated.

(Thomas *et al.*, 1973). We decided to investigate the use of xeroradiography with this ultra-high kilovoltage technique in the assessment of occupational lung diseases.

Initial exposures of 60-80 mas at 200 kV were considered excessive for normal use and different radiographic techniques were then investigated. It was found that an air gap, with 152.4 mm (6 inches) separation of the patient from the film, and a focus-film distance of 3 m (10 ft), gave equally good xeroradiographs with a reduction of x-ray exposure. After further experimentation we found that the insensitivity of the xeroradiographic plate to scattered radiation made it possible to do direct radiography without grids or air gaps at 200 kV, and in the interests of prolonging the life of our x-ray tube, the focus-film distance was reduced to approximately 1.3 m (4½ ft). With this technique our exposure range was from 10-30 mas at 200 kV, using a twelve-pulse three-phase generator with 4 mm of

aluminium tube filtration. The direct xeroradiographs obtained showed superb detail comparable with those obtained with grids. The radiation exposure to the subject under these circumstances is slightly more than that given by a conventional low kV film, but considerably less than that from mass miniature radiography.

Results

One hundred and fourteen workers were studied by xeroradiography, all of whom were miners with either silica or asbestos exposure or both, and the results were compared with our conventional ultra-high kilovoltage chest radiographs taken at 200 kV, as well as with 60-75 kV chest films. The 200 kV chest films had been previously shown to be superior to low kilovoltage films for the diagnosis of occupational lung diseases (Thomas *et al.*, 1973), and this was confirmed in our study.

The xeroradiographic films are too small to include the entire lung fields; for this reason, depending on the findings in conventional films and the nature of the occupational dust exposure, the upper or lower two-thirds of the lung field were xeroradiographed, and occasionally both to include the whole lung on each side.

After examining both positive and negative xeroradiographs we decided that the positive mode gave more information and was easier to interpret. On the positive xeroradiograph the relatively unexposed areas, such as ribs and heart, are blue and the heavily exposed areas of the lung are white, with lung markings being blue. This is the opposite to the conventional radiograph where heavily exposed areas are black and unexposed areas white. It is of interest that von Schertel *et al.* (1975) were of the opinion that the negative mode gave better contrast with their lower voltage (120 kV) technique.

Almost without exception the xeroradiographs show mediastinal structures, the trachea, carina and main bronchi as well as the aorta, better than 200 kV radiographs. The lung vascular markings are shown with better contrast and improved resolution so that even the smallest vessels can be followed to the periphery of the lung. The same applies to the clarity with which the lesser fissure is outlined, and there are nine examples where the lesser fissure can be demonstrated only on the xeroradiograms.

End-on bronchi in the lung fields are very clearly outlined xeroradiographically, as is calcified atheroma of the aorta.

Rib bone is shown in exquisite detail, and yet allows the underlying lung pattern to be well shown. Rib fractures, both recent and old, are very clearly shown on the 200 kV xeroradiographs, but are all but invisible in conventional 200 kV radiographs.

Fig. 4a

Fig. 4a 200 kV silver halide radiograph.

Fig. 4b

Fig. 4b Xeroradiograph. Shows clearly the inferiority of the xeroradiograph in the demonstration of sillicotic nodules. Linear shadows (bullae) and the lesser fissure are however clearly shown.

Fig. 5a 200 kV silver halide radiograph.

Fig. 5b Xeroradiograph, showing very clear pleural thickening along lateral chest wall on L and in the upper zone on the right. This was not detectable in Fig. 5a. Note wealth of detail of vascular tree.

Linear shadows, for example scars, the walls of emphysematous bullae and the linear shadows commonly seen in early parenchymal asbestosis, are usually better shown on xeroradiographs than in 200 kV conventional x-ray films (Figure 1). We had 54 cases in which linear markings were visible on the x-ray films done at 200 kV. Forty of these were much more clearly demonstrated on the xeroradiograph, 13 showed no appreciable difference between the xeroradiograph and the silver halide film image, and in only one instance was the xeroradiograph inferior to the routine film. There were 14 additional cases in which linear shadows were detected on the xeroradiographs only and were not visible at all on the 200 kV x-rays (Figure 2).

Fifty-four of our subjects had been exposed to asbestos during their mining careers. This was not a randomly selected group but comprised subjects chosen because they had fairly long service or suspicious appearances on conventional or 200 kV

radiographs. In 18 subjects fine linear shadows were seen on the 200 kV radiographs, and in an additional nine, the linear pattern was seen only on the xeroradiographs. Where shown on both types of examination, the xeroradiographic demonstration was considerably better than the routine radiograph (Figure 3). In the majority of cases the abnormal linear patterning was in the lower two-thirds of the lung fields, and would fall into category s of the International Classification (International Labour Office, 1972) with the accent on lines rather than irregular opacities.

Irregular opacities which could not be described as linear shadows (including s, t, u of the International Classification) were shown in four instances, twice better on xeroradiographs and twice worse than on the 200 kV radiographs.

Small rounded shadows due to silicosis (p, q, r of the International Classification) were very poorly shown on xeroradiographs, compared with our

Fig. 6a

Fig. 6a 200 kV silver halide radiograph.

Fig. 6b

Fig. 6b Xeroradiograph showing linear shadows and the lateral wall calcified plaque more distinctly. A calcified plaque in the diaphragm is seen only on the xeroradiograph.

Fig. 7a 200 kV silver halide radiograph.

Fig. 7b Xeroradiograph showing strikingly the impairment of perfusion due to emphysema.

200 kV films (Figure 4). There were 17 cases in whom a reading of p or q category 1/0 or higher was made. In addition there were three xeroradiographs that were read as category 0/1. The xeroradiograph reading by the International Classification was always in a lower category than the routine film reading. In some instances the discrepancy was very marked, e.g. q 3/4 on the routine film read as q 1/1 on the xeroradiograph, and in another instance q 2/2 B was actually read as 0/0 on the xeroradiograph. This difference might possibly be due to the fact that many nodular shadows are summation images made up of several smaller shadows, and the edge enhancement effect of xeroradiography which is so striking with linear markings may not have a similar effect with composite densities, each component of which is at a different depth in the lung parenchyma.

On four occasions pulmonary massive fibrosis which was obvious on conventional radiographs was hardly visible on the xeroradiographs.

Thickened but uncalcified pleura was commonly seen in asbestos-exposed persons. Uncalcified plaques are very much better shown on xeroradiographs, and four such cases were encountered (Figure 5). In four instances pleural calcification was better shown on the xeroradiographs, and in one case, a calcified diaphragmatic pleural plaque caused by asbestos exposure was visible only on the xeroradiograph (Figure 6). Lung calcifications are usually better shown on the xeroradiographs than in conventional films, but in three cases the calcifications were better shown on the 200 kV radiographs. We have noted in a previous paper (Thomas *et al.*, 1973) that small pulmonary calcifications are normally poorly shown with ultra-high kilovoltage techniques. This disadvantage of 200 kV radiography is partly offset by xeroradiography, where the critical factor appears to be the size of calcification. Very small calcifications are indistinguishable from adjacent lung markings, but slightly larger shadows, usually of 3 mm or greater, can be distinguished.

Xeroradiography, because of the superb vascular detail it demonstrates, is most useful in detection of areas of poor perfusion due to emphysema. This is of value in establishing the presence of one of the causes of respiratory disability in miners. Differences in density over a wide area are very poorly seen in xeroradiographs, however, and the hypertransradiancy of emphysema is not seen as it would be on low kilovoltage chest films. Our 200 kV routine chest films give only small differences in overall density with areas of emphysema or thromboembolic pulmonary vascular diminution, and once one has become accustomed to observing blood vessels rather than density changes, the superiority of the

xeroradiograph is striking (Figure 7).

Xeroradiography of the chest at 200 kV can be performed with acceptably small radiation exposure to the patient, and its chief advantages lie in the detection of the parenchymal and pleural manifestations of asbestosis, and in the assessment of pulmonary perfusion in emphysema and thromboembolic pulmonary disease.

The method is inferior to both conventional low kV x-rays and 200 kV examinations with film plus fluorescent screen combinations in the demonstration and grading of silicotic nodulation and pulmonary massive fibrosis.

The small size of xeroradiographs and the limited availability of suitable ultra-high kV x-ray generators makes chest xeroradiography unsuitable for routine or survey use, but it is of value in the study of pneumoconioses where linear shadows, pleural changes or impaired perfusion are a feature. A blind comparative study of xeroradiographs of men exposed or not exposed to asbestos is being planned.

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