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# OPTIMAL MAGNIFICATION RATIO OF DIRECT MACRORADIOGRAPHY IN HIGH MAGNIFICATION

## MODULATION TRANSFER FUNCTION STUDY ON SYSTEM COMBINED WITH INTENSIFYING SCREEN-FILM AND OBJECT

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ABSTRACT

Calculation of the composite modulation transfer function (MTF) of macroradiography in high magnification conducted with an X-ray tube having a very fine focal spot of 50 $\mu$ was performed with the purpose of obtaining the optimal magnification ratio.

The optimal magnification ratio of a macroradiogram taken without the object of scatterer was 4-fold when a Fuji KX medical X-ray film combined with fine definition intensifying screen of Kyokko FS was used, 5-fold with medium speed screen of Kyokko MS and 6-fold with high speed screen of Kyokko HS. The optimal magnification ratio was 8-fold regardless of the kind of intensifying screen-film system when the experiment was made with a water phantom of 5-15 cm in thickness as scatterer.

It was indicated from MTFs of macroangiograms of various magnifications obtained in animal experiments that the image quality of the macroangiogram of 6- or 8-fold magnification was superior to those of 2-, 4-, 10- and 15-fold ones.

It was concluded from the examination of macroangiograms of animals (the part of the rabbit examined was 3-5 cm thick) and macrolymphograms of patients (the examined part was 13 cm thick) that the macroradiogram of 6- or 8-fold magnification produces better findings of the fine structure of vessels than macroradiogram of other magnifications. The results accorded well with those obtained by phantom experiments with water of 5-15 cm in thickness as scatterer.

### INTRODUCTION

Since Morgan's investigation[1], modulation transfer function (MTF), in other words, optical transfer function (OTF) or contrast frequency response function (CFRF) has been applied in the evaluation of image quality of radiographic systems[2)~14)]. This method of evaluation has also been applied to macroradiography[15)~22)]. According to Ayakawa *et al.*[16)17)], the optimal

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magnification ratio of macroradiography conducted with very fine focal-spot tube with adequate combination of the intensifying screen-film system without the scatterer, was 4-fold. It is desirable moreover to obtain an optimal magnification ratio in macroradiography when a much more complex system such as the scatterer is combined with the system.

The present paper deals with the optimal magnification ratio when macroradiography is carried out in combination of an adequate screen-film and water phantom as the scatterer.

## BASIC EXPERIMENTS

An X-ray tube with very fine focal spot of 50 $\mu$ (M 511 BX-6059)[23)24)] attached to a single-phase generator with condensor inserted circuit (Toshiba KXO-12) was used for macroradiography. As test object, lead line patterns (Optiker Funk No. 5679 and No. 5863, 0.5 to 10.1 line pairs/mm, in thickness of 50 $\mu$) were used. As scatterer, a water phantom of 5, 10 or 15 cm in thickness was used. Fuji KX medical X-ray film was inserted between the intensifying screens of Kyokko FS (fine definition), MS (medium speed) or HS (high speed).

Direct macroradiography of 4-, 5-, 6-, 8-, 10- or 20-fold magnification was conducted with exposure conditions of 120–125 kVp, 2 mA, 0.025–1.0 sec. and 100 cm of focal spot-film distance. The focal spot-object distance was adequately changed in accordance with the change in magnification ratio. The film was exposed to be from 0.8 to 1.7 in ground density. The radiogram was scanned with a scanning spot of 10 $\mu$ in size of the Narumi type 250 microphotometer in perpendicular direction to the images of the lines.

By this procedure, the density distribution of the image was obtained. The square-wave response function of the macroradiographic system was calculated by Coltman's method[25)] and converted to the sine-wave response function.

(I) Influence of the intensifying screen-film system on the image quality of the macroradiographic system of various magnification ratios.

The radiograms were taken with Fuji KX combined with Kyokko FS, MS or HS. MTF of the macroradiogram thus taken in 5-, 6-, 8- or 10-fold magnification was calculated (Fig. 1).

MTF of macroradiograms of the above magnification taken in combination with Kyokko FS, MS or HS-Fuji KX became poorer in the above order of speed of intensifying screens. As the magnification ratio became higher, the difference in image deterioration due to difference in speed of intensifying screens became less.

(II) Optimal magnification ratio of macroradiogram.

The optimal magnification ratio obtained by changing the combination of

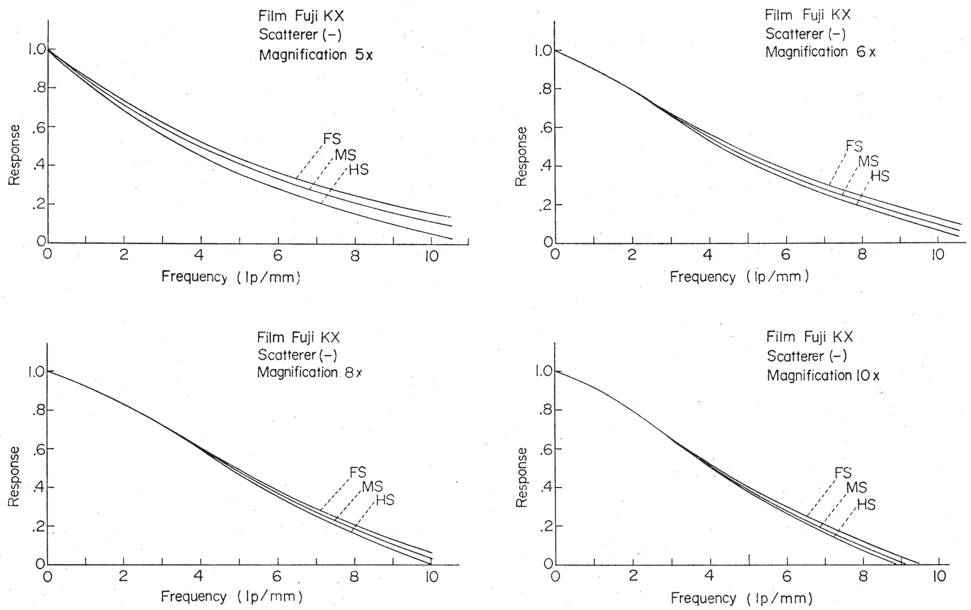


FIG. 1. MTF curves of macroradiograms of 5- to 10-fold magnification taken by a very fine focal-spot X-ray tube with three kinds of speed of the intensifying screen-film system.

MTF of the macroradiogram of each magnification becomes poorer, as the speed of the intensifying screen of Kyokko FS fine definition, Kyokko MS medium speed or Kyokko HS high speed increases in this order, but the difference of MTF due to difference in speed of the intensifying screens becomes less, as the value of the magnification ratio rises.

intensifying screen-film system was examined by taking the radiogram of the test object attached to the water phantom, scatterer, of variable thicknesses.

(a) By using an intensifying screen-film system of combination with Kyokko FS, MS or HS and Fuji KX, macroradiograms of 4-, 5-, 6-, 8- and 10-fold magnifications were taken without the water phantom. MTFs were calculated (Fig. 2).

MTF of the macroradiogram of 10-fold magnification was superior to those of 4- to 8-fold magnifications in the lower region of spatial frequency, but was inferior to others of higher regions of spatial frequency of 6 line pairs/mm (lp/mm). Each of the MTF curves turned its amplitude in order, when the spatial frequency changed from low to high. MTF of the macroradiogram of 4-fold magnification was superior to others and of 5-, 6-, 8- and 10-fold became worse in this order in the higher spatial frequency region of 9 lp/mm, while of 5-fold magnification was superior to others in the spatial frequency region of 7 to 9 lp/mm, when the fine definition intensifying screen-film system was applied (Fig. 2, A).

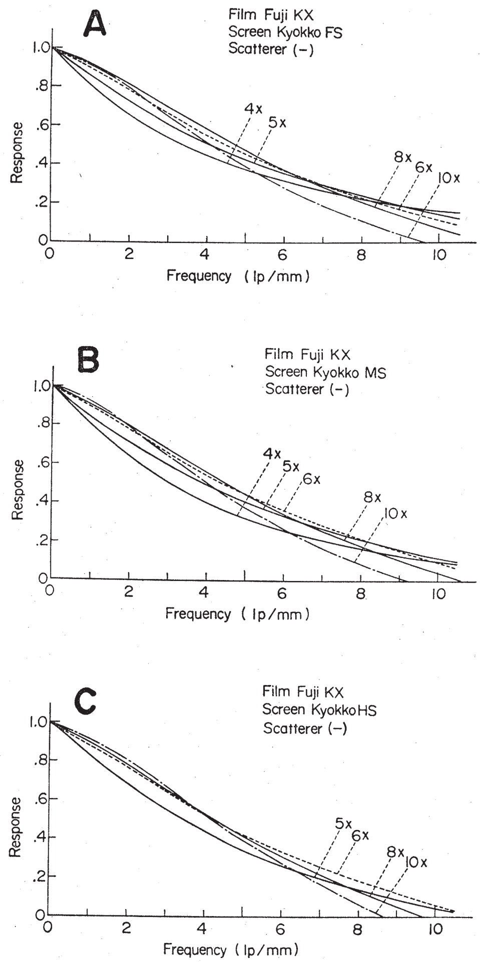


FIG. 2

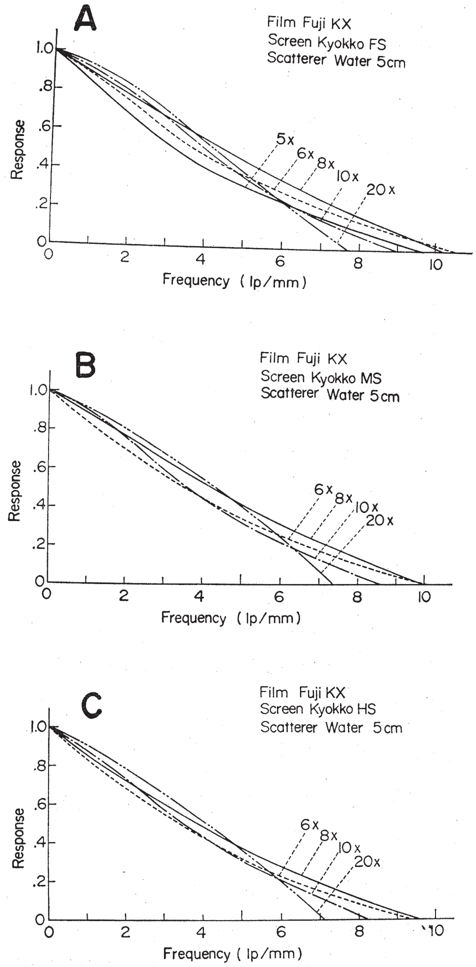


FIG. 3

FIG. 2. MTF curves of macroradiograms of 4- to 10-fold magnification with combination of the fine definition intensifying screen-film system (A), medium speed (B) and high speed (C), without the scatterer.

A : MTF of macroradiogram of 4-fold magnification is superior to others in the higher spatial frequency region of 9 lp/mm.

B : MTF of macroradiogram of 5-fold is superior to others in the higher spatial frequency region of 8 lp/mm.

C : MTF of macroradiogram of 6-fold is superior to others in the higher spatial frequency region of 5 lp/mm.

FIG. 3. MTF curves of macroradiograms of 5- to 20-fold magnification combined with water phantom of 5 cm in thickness inserted in the intensifying screen-film system of fine definition screen (A), medium speed (B) or high speed (C)-Fuji KX medical X-ray film.

A : MTF of macroradiogram of 6- or 8-fold magnification is superior to others in the higher spatial frequency region.

B and C: MTF of macroradiogram of 8-fold is superior to others in the higher spatial frequency region.

Similarly, MTF of the macroradiogram of 5-fold magnification was superior to others and the 4-, 6- and 8-fold ones became worse in this order at the spatial frequency region of 10 lp/mm, while that of 6-fold magnification was superior to others in the spatial frequency region of 5 to 8 lp/mm, when the medium speed intensifying screen-film system was applied (Fig. 2, B).

MTF of the macroradiogram of 6-fold magnification was superior to others in the higher spatial frequency region of 5 lp/mm and the 5-, 8- and 10-fold ones became worse in this order at the spatial frequency region of 8 lp/mm, when the high speed intensifying screen-film system was applied (Fig. 2, C).

As the purpose of macroradiography is to examine the fine structure of the tissue, the optimal magnification ratio is considered that in which the macroradiogram gives the best image quality at a spatial frequency as high as possible, that is, in which an object as small as possible can best be imaged on the macroradiogram.

Therefore, in this case, it is concluded that in clinical use the optimal magnification ratio is 4-fold, when the Fuji KX medical X-ray film combined with the fine definition intensifying screen of Kyokko FS without the water phantom is used, and that it is 5-fold, when combined with the medium speed intensifying screen of Kyokko MS, and that it is 6-fold, when combined with the high speed intensifying screen of Kyokko HS.

(b) By using an intensifying screens-film system that is the combination with Kyokko FS, MS or HS and Fuji KX, macroradiograms of 5-, 6-, 8-, 10- and 20-fold magnification were taken with the water phantom of 5 cm in thickness, and the MTFs were calculated (Fig. 3).

MTF of the macroradiogram of 20-fold magnification was superior to those of 5- to 10-fold magnification in the lower region of spatial frequency, but was inferior to others in the higher region of spatial frequency of 4 lp/mm. As the spatial frequency changed from low to high, each of the MTF curves turned its amplitude in order.

MTF of the macroradiogram of 8-fold magnification was superior to others in the higher spatial frequency region of 4 lp/mm, though that of 6-fold magnification was superior to that of 8-fold at the extremely higher region of spatial frequency of 9.5 lp/mm, when the fine definition intensifying screen-film system was applied (Fig. 3, A).

MTF of the macroradiogram of 8-fold magnification was also superior to others in the higher spatial frequency region of 5 lp/mm, when the medium speed or high speed intensifying screen-film system was applied (Fig. 3, B or C).

The optimal magnification ratio is, therefore, 6- to 8-fold in this case, when the Fuji KX medical X-ray film combined with the intensifying screen of Kyokko FS fine definition with the water phantom of 5 cm in thickness is used, and it is 8-fold, when combined with the intensifying screen of Kyokko

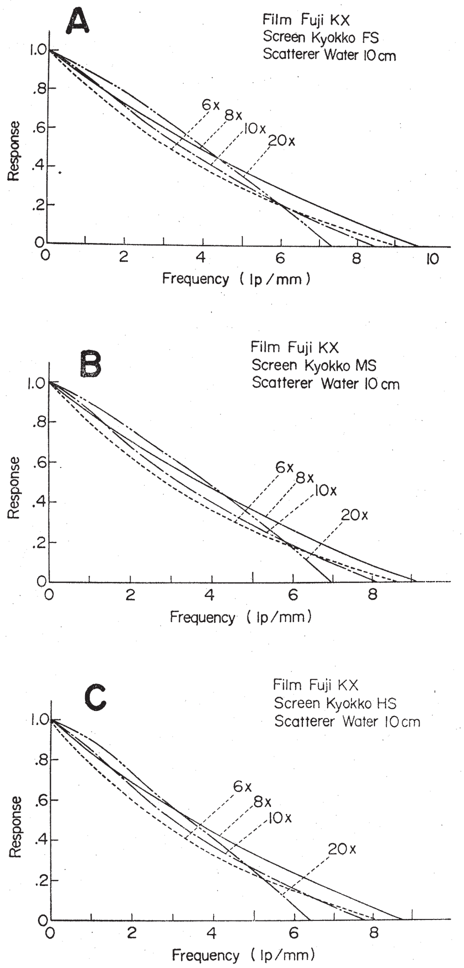


FIG. 4. MTF curves of macroradiograms of 6- to 20-fold magnification combined with water phantom of 10 cm in thickness inserted in the intensifying screen-film system of fine definition screen (A), medium speed (B) or high speed (C)-Fuji KX medical X-ray film.

MTF of macroradiogram of 8-fold magnification is superior to others in the higher spatial frequency region, regardless of the intensifying screen-film system combined.

MS (medium speed) or HS (high speed) is used.

(c) By using an intensifying screens-film system that is the combination with Kyokko FS, MS or HS and Fuji KX, macroradiograms of 6-, 8-, 10- and 20-fold magnification were taken with the water phantom of 10 cm in thickness, and the MTFs were calculated (Fig. 4).

MTF of the macroradiogram of 8-fold magnification was greatly superior to those of 6-, 10- and 20-fold magnification in the higher spatial frequency of 4.5 lp/mm and that of 6-, 10- and 20-fold one became worse in this order in the higher spatial frequency region (Fig. 3, A, B, C).

The optimal magnification ratio is, therefore, 8-fold in this case regardless of the intensifying screen-film system applied, when the experiment is made with the water phantom of 10 cm in thickness.

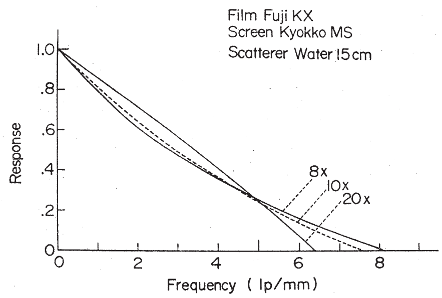


FIG. 5. MTF curves of macroradiograms of 8- to 20-fold magnification combined with water phantom of 15 cm in thickness inserted in the medium speed intensifying screen-film system.

MTF of macroradiogram of 8-fold magnification is superior to those of 10- and 20-fold in the higher spatial frequency region.

(d) By using the intensifying screen-film system that is the combination with Kyokko MS and Fuji KX, macroradiograms of 8-, 10- and 20-fold magnification were taken with the water phantom of 15 cm in thickness, and the MTFs were calculated (Fig. 5).

MTF of the macroradiogram of 8-fold magnification was superior to those of 10- and 20-fold magnification in the higher spatial frequency of 5 lp/mm.

The optimal magnification ratio is 8-fold in this case, when the Fuji KX medical X-ray film combined with the medium speed intensifying screen of Kyokko MS was used with the water phantom of 15 cm in thickness.

If the experiment should be made with the water phantom of 15 cm in thickness by using the Fuji KX combined with the high speed intensifying screen of Kyokko HS or with the water phantom of greater than 15 cm in thickness, MTF of the macroradiogram of 10-fold magnification might be superior to that of 8-fold.

From the results of these basic experiments, it is concluded that; the image quality of macroradiography of high magnification becomes, really, more deteriorated due to combination of the higher speed intensifying screen-film system and of the greater thickness of the scatterer. It is better to get a higher magnification ratio in order to prevent the image deterioration of macroradiography as much as possible, as the value of the optimal magnification ratio becomes higher in such a case. The optimal magnification ratio also changes according to the spatial frequency of the test object.

## ANIMAL EXPERIMENT

A conventional angiogram as well as macroangiograms of direct 2-, 4-, 6-, 8-, 10- and 15-fold magnification of the lower extremity of the rabbit (body weight: 3 kg) were taken with an X-ray tube having a focal spot of 50 $\mu$. The thickness of the soft tissues of the extremity radiographed was measured 3 to 5 cm.

The high-speed medical X-ray film of Kodak royal blue brand and the medium-speed intensifying screen of Kyokko MS were used. The exposing

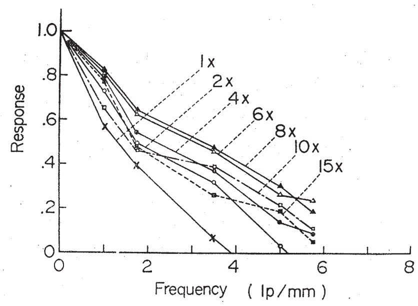


FIG. 6. MTF curves of conventional- and macroangiograms of the rabbit of 2- to 15-fold magnification using Kodak royal blue medical X-ray film combined with medium speed intensifying screen of Kyokko MS.

MTF of macroangiogram of 6- or 8-fold magnification is superior to the others.

factors were 120 kVp, 1.5 mA, 0.03 sec. and 100 cm of the focal spot-film distance. As for the magnification ratio, the distance from the focal spot to the surface of the examination table was changed according to the individual magnification ratio.

After pervenous whole anesthetization of the rabbit with isozol, catheterization was performed through the exposed right femoral artery, with an opaque catheter (Cook, Pert–4. 1) and the catheter-tip was inserted into the left common iliac artery 2 cm from the bifurcation. Radiograms were taken immediately after contrast medium (3 ml of 65% angiografin) was injected through the catheter.

Images of five different vessels of 85–600 $\mu$ in diameter of the same region by conventional- and macroangiograms were scanned perpendicularly to the direction to the vessels with the scanning spot of 10 $\mu$ in size of the microphotometer. Square-wave response functions were calculated from the curves obtained[26)27)], and were compared with MTFs of the phantom experiments (Fig. 6).

MTFs obtained from the vascular images of the rabbit indicated that the image quality of the macroradiogram of 6- or 8-fold magnification was superior to others.

The optimal magnification ratio was 6- to 8-fold in this animal experiment and coincided with the results of Fig. 3 of the phantom experiments.

Actual macroangiograms of 2-, 4-, 6- and 8-fold magnification indicated that it was better to image the fine vessels with 4-fold magnification technique than with 2-fold, and that it was best with 6- or 8-fold ones to image the finer structure of the vessels (Fig. 7).

## CLINICAL APPLICATION

Conventional lymphogram and macrolymphograms of direct 4- or 8-fold magnification of a 60 year-old female after mastectomy for left breast cancer complicated by edema of the arm (13 cm thick) were taken by using Kodak royal blue brand X-ray film in combination with Kyokko MS intensifying screen.

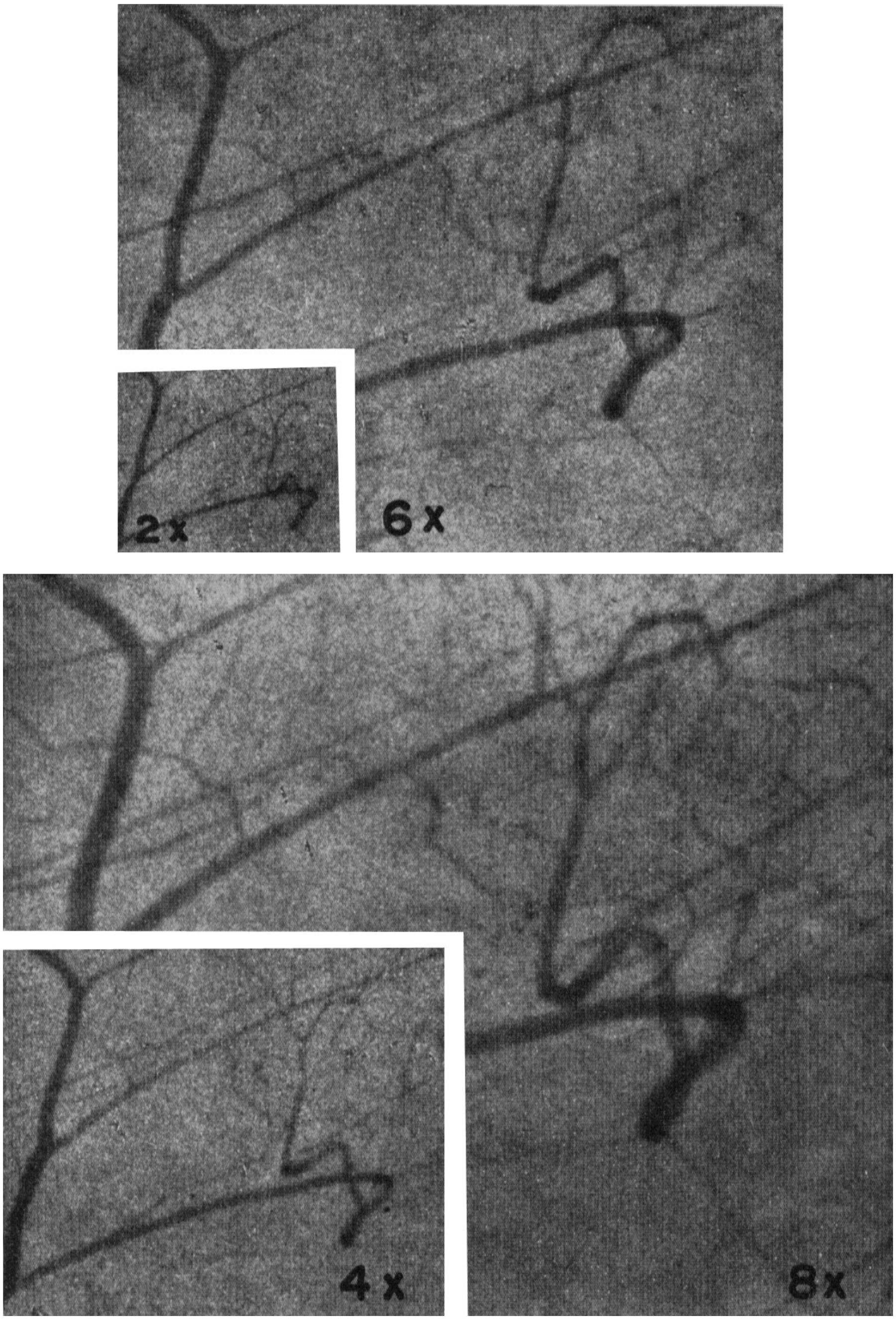


FIG. 7. Macroangiograms of the rabbit of 2-, 4-, 6- and 8-fold magnification. Fine vessels are imaged more on the macroangiogram of 4-fold magnification than of 2-fold. Fine structure of the vessels is better imaged on macroangiogram of 6- or 8-fold magnification than of 4-fold.

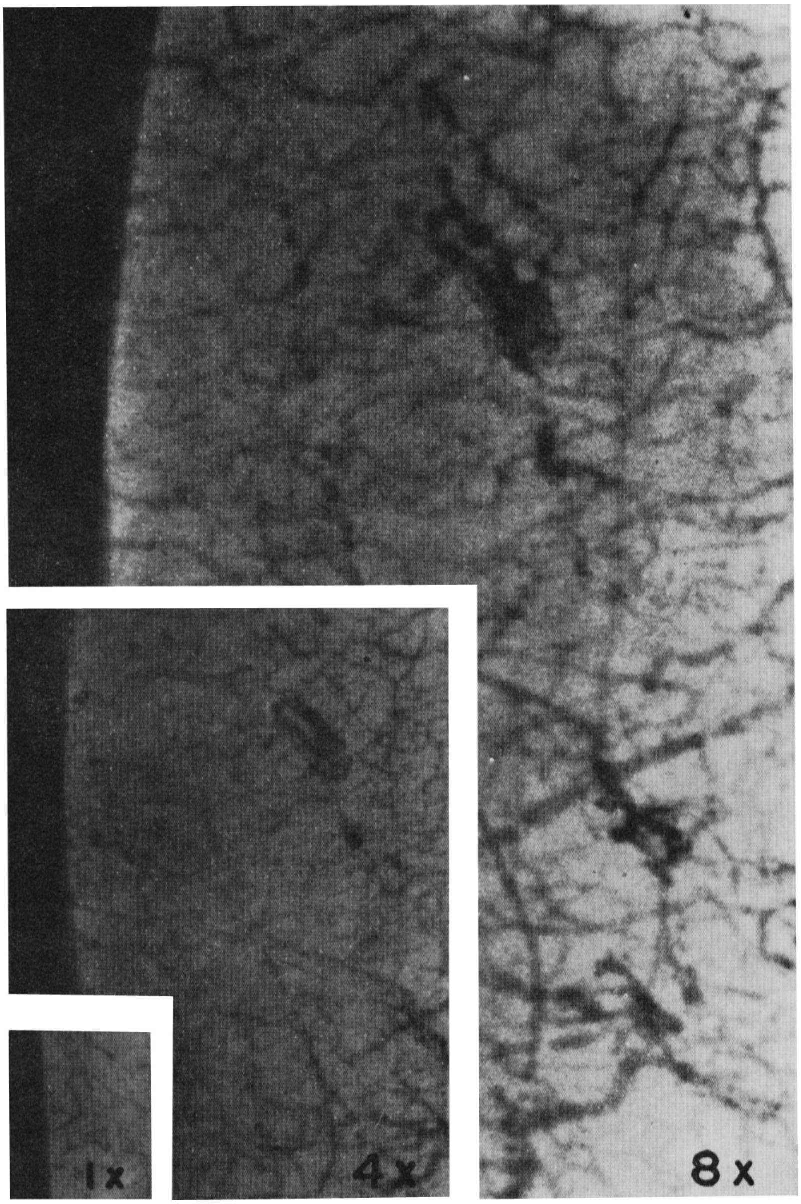


FIG. 8. Conventional- and macrolymphograms of 4- and 8-fold magnification. Fine lymph vessels not detectable on conventional are imaged on macrolymphogram of 4-fold magnification and much better on 8-fold.

Two X-ray tubes were used for this study. The tube having the focal spot of 1.5 mm in size was used for conventional lymphography. The exposing factors were 48 kVp, 200 mA, 0.1 sec. and 150 cm of the focal spot-film distance, while the other tube having the focal spot of 50 $\mu$ in size was used for macrolymphography of 4-fold magnification. The exposing factors were 120 kVp, 3 mA, 0.06 sec. and 100 cm of the focal spot-film distance, and for the 8-fold magnification were 120 kVp, 3 mA, 0.15 sec. and 120 cm of the focal spot-film distance.

The findings of lymphograms were compared with each other.

The number of lymph vessels in an area of $2 \times 2$ cm of the conventional lymphogram located in the midline parallel to the humerus or the diagonal line intersected, was 7 or 8, while it was 26 or 24 in the same area of the macrolymphogram of 4-fold magnification, and 40 or 39 in the 8-fold one (Fig. 8).

From these results, it was concluded that the structure of fine lymph vessels not detectable on the conventional lymphogram is revealed on the macrolymphogram of 4-fold magnification and much more on the 8-fold one. The conclusion coincided with the results shown in Fig. 4 or Fig. 5.

## DISCUSSION

When radiographed clinically, the object itself becomes a source of image deterioration as well as that of information, as the object contributes to be a scatterer. Rossmann[28] described that one-dimensional spatial frequency spectrum of a cylindrical object embedded in absorption medium can be calculated theoretically from the density distribution of its image by an inverse Fourier transformation, and Doi[10] stated that a two-dimensional spatial frequency spectrum is calculated by introducing a discrete strata model theoretically and that comparisons between calculated and actual X-ray images of smaller cylindrical and square objects show good correspondence. But it is essential for images radiographed to be dealt with from three-dimensional aspects in clinical examination.

Thus, by considering that the object is equal to the scatterer, water phantom experiments were performed in order to evaluate how the scatterer influenced the composite MTF of the macroradiographic system. The composite MTF of the macroradiographic system $I(\nu)$ is obtained by

$$I(\nu) = F\left(\frac{b}{a+b}\nu\right) \cdot Sf\left(\frac{a}{a+b}\nu\right) \cdot O(\nu) \qquad (1)$$

where $F(\nu)$ is the MTF of the focal spot of the X-ray tube, $Sf(\nu)$ the MTF of the intensifying screen-film system, $O(\nu)$ the MTF of the object, $a$ and $b$ the distances between focal spot and object, and between object and film, respectively. According to equation (1), the higher the magnification ratio of the macroradiography becomes, the worse $F(\nu)$ becomes and the better $Sf(\nu)$. $O(\nu)$ is a variable of many factors such as the thickness of the scatterer, its absorption coefficient, secondary scattered radiation, exposing factors and so on, which are included in the object. $O(\nu)$ becomes better, as the magnification ratio of the macroradiography increases and worse, as the thickness of the scatterer increases. So, changing the combination of the magnification ratio, the thickness of the scatterer and the intensifying screen-film system was performed in this experiment.

From equation (1), if $Sf(\nu)$ and the thickness of the scatterer, a factor of $O(\nu)$ are fixed, the relationship between $a$ and $b$ that is the magnification ratio, where $I(\nu)$ becomes best due to $O(\nu)$, may be obtained.

Rossmann *et al.*[27] calculated MTF of the angiographic system using a blood vessel phantom constructed by drilling cylinders 2 cm in length in a plastic plate 0.5 cm thick which were filled with radiopaque medium used in cerebral angiography. In this paper, from actual macroradiograms of various magnifications, MTFs were calculated and they coincided with those of the phantom experiments.

It was also clarified that there is an optimal magnification ratio according to the spatial frequency of the object observed in the macroradiographic system. Doi[22] stated this fact in a recent paper. In the lower spatial frequency region, the best image quality may be obtained by macroradiography at much higher magnification, and in the higher spatial frequency region, the optimal magnification ratio changes due to combination of the intensifying screen-film system and the scatterer added.

From the results, macroradiography of 6- to 8-fold magnification should be recommended, using the fine definition intensifying screen-film system, when subjects such as the upper extremity of the adult are radiographed, equivalent to water of 5 cm in thickness, and that 8-fold magnification be recommended using the medium speed intensifying screen-film system, when such as the lower extremity and chest of the adult which are equivalent to water of 10 cm in thickness are to be radiographed, and that 8- to 10-fold magnification be recommended using the high speed intensifying screen-film system, in case of the abdomen of the adult which is equivalent to water of 15 cm in thickness.

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