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Optimization of Digital Mammography Resolution Using Magnification Technique in Computed Radiography[1]

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Purpose: To determine whether magnified digital mammography using a computed radiography system can produce better spatial resolution by reducing the focus-object distance, and to define the optimal magnification factor when a large x-ray tube focal spot is used for digital mammography using a CR system.

Materials and Methods: Digital images obtained using computed radiography of a breast phantom were obtained using various magnification factors. Up to twelve acrylic blocks each measuring one centimeter in height were used to increase the distance between the breast phantom and the base plate (screen holder), in order to create the magnification images. The large (0.3 mm) focal spot of the x-ray tube was used for the entire series of images. Three radiologists participated in the evaluation of the images, in order to determine which had the best resolution. The resolving ability of the line pair structures and image clarity of the detectable artificial microcalcifications (specs) were the two factors used to determine the resolution of the images. The images were not compressed aFnd the viewing conditions, including the magnification factors, brightness and contrast, were fixed. The images were displayed on four high resolution PACS dedicated monitors (5 mega pixel LCD, BARCO Belgium).

Results: A focus-object distance of 590 mm and a source-to-image receptor distance of 650 mm (set by the manufacturer) resulted in the best resolution, when combined with a magnification factor of 1.1. All three radiologists agreed on this result. Two of the radiologists believed that at least two more line pairs were better separated on the magnified image having the best resolution than on the unmagnified image, while one radiologist believed that three more line pairs were better separated on this magnified image. Using images with still larger magnification factors did not improve the resolution due to edge blurring. It was easier to determine the resolving power by means of the line-pair structures than by assessing the clarity of the artificial microcalcifications

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(specs). A 10% decrease in focal spot-object distance resulted in a 21% increase in radiation to the breasts.

Conclusion: Magnified digital breast images taken with a computed radiography system using a large focal spot produced better quality images, because of their utilizing more pixels per volume of the breast phantom with a minimal increase in radiation dosage.

Digital imaging techniques, including digital mammography, have many advantages over traditional screen-film mammography in that each part of the breast imaging chain - i.e. image acquisition, image storage and image display - can be optimized. The use of detectors in digital radiography (DR) or photostimulable storage phosphor screens in computed radiography (CR) can improve lesion detection, due to the increased efficiency of absorption of the incident x-ray photons and larger dynamic range associated with these devices. In addition, digital image processing that uses algorithms and viewing software to control the image contrast and to provide adjustable viewing windows also helps to further improve lesion conspicuity (1 - 3). Digital imaging would also facilitate the use of computer-aided detection and diagnosis, as well as teleradiology.

Because of these advantages, the use of PACS (Picture Archiving and Communication System) has now become widespread worldwide, especially in Korea, where more than 70 large hospitals have installed these filmless PACS systems. Despite the rapid spread of PACS, digital mammography is seldom performed in hospitals equipped with this system, most likely due to radiologists' concerns that digital mammography using CR may not have sufficient spatial resolution for accurate lesion detection and characterization, compared to screen-film mammography. Even so, using screen-film systems in hospitals that utilize filmless PACS may cause increased expense and inconvenience. Most Korean hospitals with filmless PACS have CR systems for general radiography, and CR mammography can be added without additional cost, with the exception of the cost of the image plates. Dedicated full field digital mammography systems, however, can cost $250,000 - $500,000 (4), and some require independent viewing systems, separate from PACS, which can be both inconvenient to use and costly.

The improvement in spatial resolution of CR systems may help to further convince radiologists to use these useful digital images in screening mammography, and this could easily be achieved by decreasing the focus-object distance (FOD). However, edge blurring poses a problem in the magnified images obtained using a large focal spot, since the limited number of pixels in the currently available CR (pixels in the phosphor screen) and DR (pixels in the detector) systems causes the image resolution to be inferior that associated with the much smaller granules (1.0 - 1.5 μm) in film emulsions (5).

To the best of our knowledge, there have been no experimental studies designed to evaluate the optimal magnification factors needed to improve the spatial resolution in full-field digital mammography using CR. The purpose of this study is to evaluate the optimal magnification factors to use, in order to improve the spatial resolution of digital mammography. Moreover, we also suggest that manufacturers consider providing a base plate with a shorter FOD that can be used for magnified CR mammography.

Materials and Methods

System and Image Acquisition

In order to create images with various magnification factors, twelve acrylic blocks, each with a height of one centimeter, were used to support a breast phantom. Twelve magnified digital images and one non-magnified digital image were obtained on a conventional mammography unit (Mammomat 3000, Siemens, Germany) using the large focal spot (0.3 mm) of the x-ray tube. This experiment was also attempted using the small focal spot (0.1 mm), but the continuous use of this focal spot resulted in tube failure and this study was therefore discontinued. The manufacturer advised against using the small focal spot for routine screening mammography, due to the risk of overloading the tube. The phantom (CIRS, tissue-equivalent phantom for mammography model 011A, Norfork, Virginia U.S.A.) was placed on top of one of the acrylic blocks which was itself placed on the top of the base plate, as shown in Fig. 1.

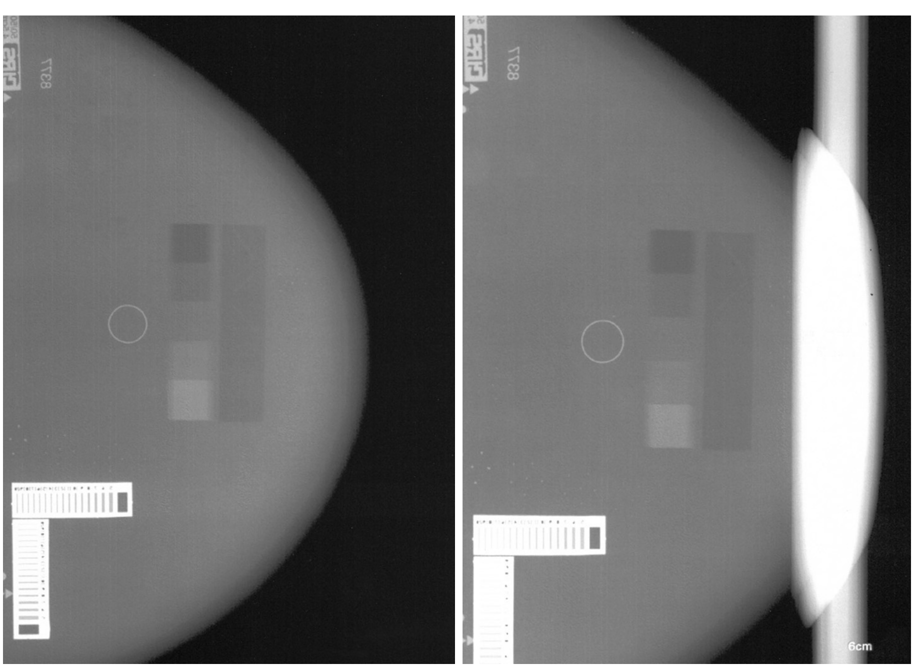
The moving grid was turned on during exposure. All magnified images were taken at one-block increments and numbered accordingly. Single-sided image plates

(Fuji, Japan) measuring 18×24 cm (1770×2370 pixels) were used and processed in high quality mode (100 μm). All images were obtained using exposure settings of 30 kVp and 40 mAs (the median exposure used in our department for CR mammography), with automatic exposure control switched off. The source-to-image receptor distance (SID) was 650 mm (set by the manufacturer), and the magnification factors were calculated by dividing the distance from the focal spot to the phantom by the distance from the focal spot to the receptor (5).

Evaluation of Images

Three radiologists, each with more than three years' experience of reading mammograms, participated in the evaluation of the images, in order to determine the best spatial resolution. The number of detectable microcalcifications (specs of 0.165 to 0.400 mm) and the clarity of the line pair structures (20 lp/mm) contained in each phantom image were used to determine its resolution (6). The images were not compressed and the same viewing conditions (image size, monitors and room illumination) were used for each image. Since the line pair structures were too small to evaluate on the original images, they were displayed with a magnification factor of 2.5 (Fig. 2, 3) on 4 LCD monitors (5 mega pixel LCD, Barco, Belgium). The radiologists were asked to select the image with the greatest number of detectable calcifications and for which the clarity of the line-pair structures was the highest, on monitors having preset brightness and contrast levels. When the best image could not be selected, they were asked to choose two additional images that had similar resolutions.

Fig. 1. A breast phantom is supported by multiple layers of acrylic blocks, each with a height of 10 mm. The true magnification factor is slightly higher, since most of the structure in the phantom (breast) will have a shorter FOD (Focus to Object Distance).

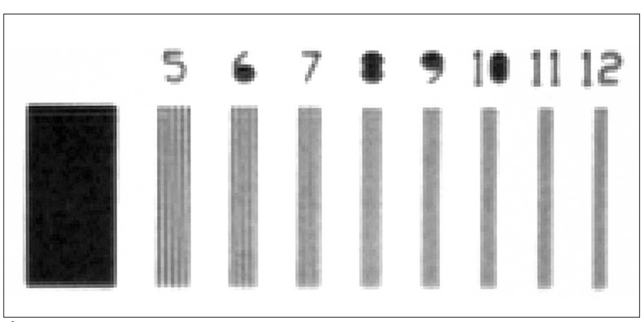


A B

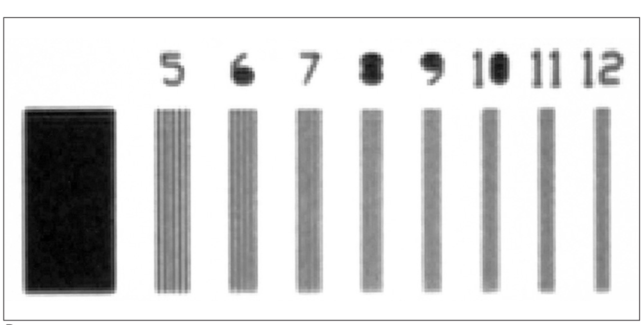
Fig. 2. Line-pair bar in the non-magnified image (A) and image taken with an FOD that is 60 mm shorter (B) was too small to evaluate. The lenticular shaped opaque densities at the margin of the images are from the acrylic blocks.

Results

The observers unanimously agreed that all of the magnified images had better resolution than the non-magnified image, and that the image taken with an FOD of 590 mm (magnification factor of 1.1) gave the best result. In each case, all three radiologists were in agreement as to which was the best image, despite the fact that the differences between the two immediately neighboring images were sometimes quite subtle. When the non-magnified image was compared with the image taken with a magnification factor of 1.1, all of the observers agreed that there was a significant improvement in the line pair separation and clarity. Artificial calcifications (specs) were more clearly seen on the magnified images, but the number of visible smaller specs did not increase significantly (Table 1). Edge blurring appeared on the images with larger magnification factors (Fig. 4). Despite the use of the same exposures for all images, there appeared to be slightly more background noise on the non-magnified images, although the significance of this finding is not certain. The images were not displayed in random order and the observers were aware that they were displayed in the order of increasing number of one-block increments. Due to the shorter distance from the source of radiation to the breast phantom in the case of magnified digital mammography, there is a 21% increase in the amount of absorbed radiation (6.5^2 / 5.9^2) (5).



A



B

Fig. 3. Line-pair bars are magnified 3.5 times and the image taken with an FOD of 590 mm (B) showed good separation of the line-pairs compared to the image with an FOD of 650 mm (A).

Discussion

Mammography is now one of the most common imaging examinations that directly results in the reduction of mortality from disease. There have been remarkable advancements in the quality of screen-film mammography over the past 25 to 30 years. Although substantial advances have been made in non-mammographic breast imaging techniques such as ultrasonography (US) and magnetic resonance (MR), screen-film mammography is the only modality to be used as a screening (7, 8).

Digital mammography is still in its infancy when compared with screen-film mammography. The latter has had the benefit of more than three decades of clinical use and technological improvement. With the current rapid development in computer-related hardware, however, technological improvements in digital imaging can be expected to occur at a faster rate than that of screen-film mammography. One of the most widely used methods of acquiring digital images is CR, a digital image acquisition and processing system for static projection radiography. Another promising method is digital radiography, which uses digital electronic detectors such as thin film transistor arrays, or charge coupled devices (CCD) integrated with various processing techniques.

CR uses a phosphor screen (image plate) with energy storage capability as an x-ray image receptor. The screen is contained in a standard size radiographic cassette similar to a screen-film system. After exposure, the cassettes are transferred to a reader system, where the image plates are scanned using a finely focused laser beam that stimulates luminescence in a manner which is proportional to

Table 1. Comparison between the Magnified Image with the Best Quality (Magnification Factor of 1.1) and the Non-magnified Image

	Radiologist 1	Radiologist 2	Radiologist 3
Line pair separation	+ + +	+ + +	+ + +
Clarity of line pair	+ + +	+ + +	+ + +
Visible specs	-	+	-
Clarity of specs	+ +	+ +	+

Three radiologists scored on 4 categories. + + +: definite improvement, + +: moderate improvement, +: subtle improvement. - : no significant improvement.

the local X-ray exposure. The luminescence signal is then converted to an electrical signal and digitized (9 - 11).

The resolution of the digital images in both CR and DR will continue to improve and the price of the systems is expected to decline significantly. FCR (Fuji Computed Radiography, Fuji Medical, Japan) image plates have a limited number of phosphors or pixels (1770×2370 pixels for 18×24 cm IP), that limit the resolution of the images. Improving the resolution requires that the number of pixels per unit area of the phosphor screen be increased, and that the efficiency of the detectors be enhanced. Double-sided image plates with double laser readers in the processing units have been introduced for the purpose of providing improved resolution in CR mammography. Another way of improving the resolution is to utilize a larger area of the phosphor screen per unit volume of the object, by decreasing the distance from the x-ray source to the object. In the case of conventional screen-film mammography systems, which have a much larger number of pixels in the form of much smaller silver halide crystals (1 - 1.5 microns compared to 100 microns in CR) in the film emulsion, edge blurring is a major factor affecting the quality of magnified images taken using a large focal spot. Using a smaller focal spot can further reduce the amount of edge blurring, but overloading the x-ray tube can be expensive, and it is therefore not feasible to use a smaller focal spot for screening mammography. Our experiment demonstrates that a significant increase in resolution can be obtained, by simply decreasing the focus-object distance from 650 mm to 590 mm. As the FOD is further decreased, edge blurring starts to occur and the improvement in the resolution is lost. Decreasing the FOD, however, has the disadvantage of slightly increasing the average glandular absorption radiation dose to the breast. Studies have shown that the speed of the computed radiography system, which uses phosphor plate imaging, approximately equates to a 300-speed screen-film system (12). The use of a higher kVp and lower mAs may be considered, since the subtle decrease in contrast that this produces can be compensated for during image processing, as well as by means of the viewing software, in order to control the brightness and contrast. It has also been noted that the breast pattern has little influence on the glandular absorption radiation dose (13) in a screen-film system, and it can therefore be assumed that this would also be the case with digital mammography. There is no increase in file size caused by using magnified images when they are acquired and stored as raw data, but there is an increase of about 20 - 25% when loss-less compression (DPCM) is used. This increase in file size is due to the partial replacement of the uniform density of the background by the image of the breast on the magnified images. Manufacturers of mammography units should perhaps consider making a base plate (or a compression device) with a focal spot to object distance that is ideal for CR mammography, and this could perhaps also be done for flat panel DR systems, in order to improve the resolution.

The usefulness of digital images in mammography has been significantly underrated. Many radiologists with experience in reading screen-film mammography are reluctant to accept CR mammography with a pixel size of 100 ?m for screening mammography because of its lower resolution. However, this disadvantage can be partially compensated for by appropriate image processing and the viewing flexibility of the digital images.

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컴퓨터촬영(CR)에서 확대촬영술을 이용한 디지털 유방촬영 해상도의 최적화[1]

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목적: 확대 디지털 유방촬영술에서 초점 - 대상간 거리를 줄임으로써 공간해상도를 향상시킬 수 있는지 알아보고, 디지털 유방촬영술에서 대초점의 엑스선관을 이용할 경우 가장 좋은 해상도를 보이는 확대정도를 알아보고자 하였다.

대상과 방법: 확대정도를 달리하며 다양한 유방 팬톰 디지털영상을 얻었다. 1 cm 높이의 아크릴판 12개를 사용하여 팬톰과 영상판사이의 거리를 점차적으로 증가시켜 가면서 확대된 이미지를 얻었으며 엑스선관의 초점은 0.3 mm 대초점을 이용하였다. 세명의 방사선전문의가 팬톰내의 연속된 선쌍(line pair)군 및 알갱이(specs)군을 관찰함으로써 해상도를 판정하였다. 영상은 압축하지 않았으며 4대의 고해상도 LCD PACS 모니터(5 mega)에서 판정하였다.

결과: 초점에서 영상판까지의 거리가 650 mm인 유방촬영기에서 초점 - 대상간 거리가 590 mm일때 가장 좋은 해상도를 얻었다. 확대하지 않은 영상에 비하여 둘(두명의 방사선 전문의) 내지 세개(한명의 방사선 전문의)의 선쌍(line - pair)에서 구분이 더 선명하였으며, 확대율이 더 커지는 것은 해상도를 증가시키지 못하였다. 알갱이군보다 선쌍의 관찰이 해상도의 판정에 더 유용하였다. 초점 - 대상간 거리가 10% 단축 되어 약 21%의 방사선조사량의 증가가 예상된다.

결론: 확대디지털 유방촬영술은 단위 조직당 영상판(image plate)의 가용 픽셀의 수가 증가하므로 대초점(large focal spot)에서 의미 있는 해상도 향상을 주었으며 초점 - 대상간의 거리가 590 mm일 때 가장 좋은 해상도를 얻었다.