Chapter 5

Comparison of detection of micro calcifications for two clinical processing algorithms in digital mammography

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Abstract

A potential advantage of digital radiology is the possibility to apply various clinical processing techniques. Clinical processing algorithms aim to better visualize the radiological image content.

The experiment described in this paper is a quantitative method to compare the performance of 2 commercially available clinical processing algorithms for the detection of micro calcifications in digital mammograms. The first processing had been developed for general radiology. The second had been developed for general radiology and had been fine tuned for mammography. Digital mammograms from clinical practice were used. A specific number of small simulated micro calcifications with different sizes was inserted in the raw data. These composite images were then processed with the 2 different processing techniques. A reader study was conducted using hardcopy images. We report on the fraction of detected micro calcifications and False Positives (FP).

The detected fractions were obvious higher with the processing that had been fine tuned for digital mammography. The number of FP was slightly higher with this processing algorithm.

Findings in this study indicate that this evaluation method can be used to compare clinical processing protocols for the detection of micro calcifications. Additional tests should be applied to evaluate other aspects of processing such as detection of masses and evaluation of the global breast architecture.
I. Introduction

One of the potential advantages of digital radiology is the possibility to apply image processing techniques. They can be applied at different stages in the imaging chain (figure 1)(1): 1. to correct detector artefacts 2. to enhance the image content by applying clinical processing protocols and 3. to prepare the image for display. The first type of processing is based on technical measurements such as flatfield images that serve for various calibration purposes. The corrections are then applied to all images regardless of their content. Image enhancement and software for better visualization aim to better visualize the radiological image content. In this study we have focused on the imaging processing that is applied on detector corrected clinical images.

![Figure 1: Overview of image data processing at different stages in the imaging chain](image)

An ideal processing protocol should enhance the features of the whole range of possible appearing abnormalities or for the specific lesions one is looking for, and reduce the influence of anatomical background on detection and
characterisation of lesions. Various image processing algorithms such as gray scale equalization, spatial frequency processing and gray scaling are utilized in clinical practice (2),(3),(4),(5),(6). Different algorithms are currently fine-tuned and many manufacturers have developed their own processing protocols for use with their digital system, in particular also for digital mammography (2),(5),(6). The parameters of the software can be fine tuned in the radiological practice, following the preference of the radiologist. In addition, radiologists may prefer differently processed versions of the mammogram dependent on the task being undertaken. A particular setting may camouflage abnormalities while the same setting may provide the opportunity to detect other types of abnormalities. In general the outcome may depend on breast type and on noise level in the images. Sub-optimal processing may result in image degradation and misdiagnosis.

Processing may significantly impact the performance of the imaging system. To the best of our knowledge, there are no standardized protocols to evaluate the performance of the different processing algorithms. A possible approach starts from test object images that include inserts with different thickness and shape in a homogeneous background (7). Processing may perform very well on these test object images. Yet, the clinical value is not proven. It remains difficult to predict the visualisation of the anatomical background, the global look of the images over the complete dynamic range and the visibility of lesions with irregular shapes. Test objects with clinical background (8) overcome part of these shortcomings. The problem there is that only one background is available. It is not possible to check for all types of breasts. A thorough approach was followed by (9) and (10). They tried to classify different clinical processing protocols. These authors started from raw data of clinical mammograms that were then processed in different ways. All lesions were fully characterized by biopsy reports or follow-up images. In practice, this approach is very time consuming and requires a lot of input from the clinical staff. Hemminger et al. (11)
embedded simulated masses in digitised mammograms to compare which of two different image-processing algorithms would be the most valuable for mass detection.

The experiments described in this paper were performed to determine which of two processing algorithms performs the best for the detection of micro calcifications. Digital mammograms from the clinical practice were used. A well known number of small simulated micro calcifications (12) was inserted in the raw data. These composed images were then processed with the 2 different post processing techniques. Readout was done on hardcopy.

II. Material and methods

A. Description of imaging system

Images were obtained with a Siemens Mammomat 3000 (Erlangen, Germany) mammography unit. The digital detector used in this study consists of the Fuji HR-BD CR plate (Fuji Medical Systems, Japan, Tokyo). The plates were scanned and read-out with a dual-sided FCR reader (Fuji Medical Systems, Japan, Tokyo) with a 50 µm resolution. Table I summarizes the properties of the system. Figure 2 illustrates the resolution and noise of the Fuji FCR5000 MA system. Both Normalized Noise Power Spectrum (NNPS) and Modulation Transfer Function (MTF) of the system were measured under conditions that are as close as possible to those used in clinical practice for the acquisition of a standard breast. The NNPS was calculated from a flat field image of 40 mm PMMA obtained at 27 kVp, Mo/Mo under the Automatic Exposure Parameter mode. The MTF was computed from an exposure of an edge sandwiched between 40mm PMMA. The acceptance test of the system had shown the same NNPS for the various thicknesses of PMMA (results not shown) under automatic exposure control.
Table I: Properties of the Fuji FCR 5000MA

<table>
<thead>
<tr>
<th></th>
<th>Fuji FCR 5000MA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacture</td>
<td>Fuji Medical Systems</td>
</tr>
<tr>
<td>Model</td>
<td>FCR 5000MA</td>
</tr>
<tr>
<td>Detector Type</td>
<td>Indirect</td>
</tr>
<tr>
<td>Detector Material</td>
<td>Storage Phosphor</td>
</tr>
<tr>
<td>Image Area [cm²]</td>
<td>18 x 24</td>
</tr>
<tr>
<td>Image Matrix</td>
<td>3540 x 4740</td>
</tr>
<tr>
<td>Pixel Size [µm]</td>
<td>50</td>
</tr>
<tr>
<td>Displayed Image Depth [bits]</td>
<td>14 (log)</td>
</tr>
</tbody>
</table>

Figure 2: The NNPS (left) and MTF (right) of the Fuji 5000MA
B. Acquisition of mammograms/data preparation

The basic data set for this study consisted of 56 mammograms that were acquired with compression and using the routine clinical parameters, i.e. controlled by the automatic exposure control cell. The mammograms were randomly selected from 22 patients. Patients were without known pathology.

The method to insert micro calcifications was reported in (12). This approach requires raw data: in linear images, the simulation of a density consists in the multiplication of background signals with an x-ray transmission coefficient or with a pattern of x-ray transmission coefficients. Specific patterns had been developed. The whole process mimics the real image acquisition process.

The raw data from the Fuji FCR5000 MA system are log compressed. The mammogram data $SI_{\text{log}}$ were first converted to a linear scale $SI_{\text{lin}}$ with dose using the Latitude $L$ and Sensitivity $S$ values. These values are uniquely specified for each image by the histogram analysis algorithm of the storage phosphor system (5):

\[
SI_{\text{lin}} = 10^{(SI_{\text{log}} - 511 + 1023/L*Sk)*L/1023};
\]

with \(Sk = 4 \cdot \text{LOG}_{10}(S/4)\)

Micro calcifications were simulated in mammographic backgrounds with a constant system noise. In order to prevent large noise variations due to the thickness variations at the periphery of the compressed breast, only regions with constant breast thickness (13) were selected.

C. Simulation of micro calcifications

Micro calcifications were simulated starting from the x-ray transmissions of real micro calcifications (12). These real micro calcifications had been exposed at 27kVp, Mo/Mo on top of 40mm PMMA with a prototype of a CR plate and digitizer of Agfa. The micro calcifications as described for the
Agfa CR system (with magnification) were recalculated for a detector with ideal spatial resolution (MTF=1), and then remodeled for the Fuji FCR5000 MA system. Corrections for the differences in the spatial resolution were made using the method described in (12). To do so the templates of the micro calcifications were filtered by the 2D Modulation Transfer Function of the FUJI FCR5000 MA image system (12) The templates were categorized by means of their final minimal x-ray transmissions, i.e. after spatial resolution correction. There size in the image plane was expressed by the equivalent diameter as calculated for the ideally sharp detector.

Software phantoms were constructed that consist of 2 cm by 2 cm frames in which 0 to 10 templates of micro calcifications were randomly distributed. Four groups of minimum x-ray transmissions of the final templates were considered (0.9-0.92, >0.92-0.94, >0.94-0.96, >0.96-0.98). Three equivalent diameter groups were used (400-500µm, >500-600µm and >600-700µm). Fifty templates were created for each size group. The group with x-ray transmission coefficients 0.9–0.92 and smaller than 500µm were not simulated, as these templates would reflect the (unrealistic) projection of needle shaped objects. Several templates were used more than once. This results in 550 templates in total. Figure 3 plots the final peak x-ray transmission (after spatial resolution correction) as function of the equivalent diameter (as calculated for the ideally sharp detector) of the templates.
**Figure 3:** Minimum x-ray transmission (after correction for resolution of the FCR 5000MA) along their equivalent diameter (calculated for the ideally sharp digital detector)

The phantoms were multiplied pixel by pixel with the signal intensities of the mammographic backgrounds. Four different types of background were chosen: almost homogeneous fatty tissue (11 regions), a mixture of dense and fatty tissue without scattered structures (39 regions), a mixture of dense and fatty tissue with scattered fibroglandular densities (55 regions) and extreme dense homogeneous tissue (8 regions). All phantom configurations were different to avoid memorization.

**D. Processing and display**

All images were processed with the two different processing algorithms. The first algorithm had been developed by Agfa for general radiology, named MUSICA (4). The second had been developed by Fuji for general radiology but it has been fine tuned for mammography (5),(6). A short description of the two different algorithms is added in the appendix.
For the Agfa processing, the window/level, Look Up Table (LUT) and MUSICA parameters were selected as appropriate for an average image by an experienced mammographic technologist. Following criteria were applied: a unique parameter setting had to provide an acceptable image quality for all the images. Visualization of masses and micro calcifications were optimized on a few (preliminary) cases prior to this study. ‘Burned’ regions (i.e. complete black or white in the breast region) were avoided. Visualization of tissue located near the periphery of the breast was enhanced. The processing parameters are reported in table 2.

For the FUJI processing, the manufacturer’s recommended method for application to its machine-specific images was applied. These images were then printed on DI-AL Fuji laser film (8”x10”) using a FM-DPL Fuji laser printer (Tokyo, Japan). This printer has a 12 bits density resolution and a 50µm pixel resolution.

Table II: Image processing parameters of Agfa

<table>
<thead>
<tr>
<th>LUT</th>
<th>MAMMO1</th>
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<tbody>
<tr>
<td>MUSICA parameters</td>
<td>MUSICA Contrast: 4</td>
</tr>
<tr>
<td></td>
<td>Edge Contrast: 0</td>
</tr>
<tr>
<td></td>
<td>Latitude Reduction: 2</td>
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<tr>
<td></td>
<td>Noise Reduction: 0</td>
</tr>
</tbody>
</table>

E. Observer experiment

Two radiologists (C.V.O. and G.M.) with experience in digital mammography viewed the full set of images. It was explained to the observers that each phantom contained between 0 to 10 micro calcifications. The observers were asked to indicate the locations of the micro calcifications and rate their confidence about their presence using a discrete 4-point scale (with 4=very likely to be a micro calcification, 3=likely to be a micro calcification, 2=possibly a micro calcification, 1=very probably not a
micro calcification). There were no constraints on reading time and reading
distance. The observers were provided with a magnifying glass and were
encouraged to use it. Prior to the study, the observers first viewed a
training set of 10 phantoms and got feed-back after rating these phantoms.
Correct and incorrect decisions were recorded. A True Positive (TP) result
was assumed when a detected micro calcification was within the contours of
a simulated micro calcification. The False Negatives (FN) were given the
score 0. The processed digital mammograms were fully randomly
presented. The experiments were performed in a darkened room and
appropriate masking of the viewing box was used throughout. To limit the
effects of fatigue, reading sessions of about 40 minutes were held. The
radiologists took additional breaks when needed. The radiologists required
about 4 hours to evaluate all images.

F. Data analysis

For each observer, the fractions of “detected” micro calcifications for each x-
ray transmission group were plotted for each equivalent diameter group.
To do so, we used a binary score. The scores less than or equal to 1 were set
equally to 0. The scores 2, 3 and 4 were set equal to 1. This choice was
proposed by our radiologists. They would give clinical attention to micro
calcifications given a score of 2 or more. The fraction of the binary score 1
was calculated for each size groups. For all size groups and for both
observers, we calculated also the change in detected fraction for adjacent x-
ray transmission coefficients. Finally, we plotted the number of False
Positives (FP) along with their scores (i.e. 1, 2, 3, 4) for each observer.

III. Results

Figure 4 summarizes for both processing algorithms the “detected” fractions
of simulated micro calcifications for each x-ray transmission group along
their equivalent diameter. For the micro calcifications with x-ray
transmissions between 0.96 and 0.98, both processing algorithms perform
very similarly: detectability is very poor and independent of equivalent diameter size. None of the processing algorithms visualizes these very small micro calcifications. The detected fractions for the Fuji processing are larger than those for the Agfa processing. As an example, micro calcifications with an x-ray transmission coefficient between 0.92 and 0.94 and an equivalent diameter between 500µm and 600µm have detected fractions of 0.48 (C.V.O.) and 0.39 (G.M.) for the Fuji processing. The same micro calcifications show detected fractions of 0.10 (C.V.O.), respectively 0.11 (G.M.) with the Agfa processing.

The differences between the detected fractions for two adjacent x-ray transmissions, within an equivalent diameter group are summarized in Table III. For the Fuji processing, obvious differences are observed between all adjacent x-ray transmission groups. For the Agfa processing, there is only a large difference between the two lowest x-ray transmissions groups.

![Graphs showing detected fraction of micro calcifications as a function of equivalent diameter for different x-ray transmission groups.](image)

**Figure 4:** Fractions of detected micro calcifications as a function of the equivalent diameter for the different x-ray transmission groups.
Table III: Differences between the detected fractions for two adjacent x-ray transmissions, within an equivalent diameter group calculated for C.V.O. and G.M.

<table>
<thead>
<tr>
<th>x-ray transmission</th>
<th>Fuji</th>
<th>Agfa</th>
</tr>
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<tbody>
<tr>
<td>&gt;0.92-0.94 ↔ &gt;0.90-0.92</td>
<td>0.37°</td>
<td>0.53°</td>
</tr>
<tr>
<td>&gt;0.94-0.96 ↔ &gt;0.92-0.94</td>
<td>0.33°</td>
<td>0.26°</td>
</tr>
<tr>
<td>&gt;0.96-0.98 ↔ &gt;0.94-0.96</td>
<td>0.21°</td>
<td>0.09°</td>
</tr>
<tr>
<td>&gt;0.92-0.94 ↔ &gt;0.90-0.92</td>
<td>0.18°</td>
<td>0.35°</td>
</tr>
<tr>
<td>&gt;0.94-0.96 ↔ &gt;0.92-0.94</td>
<td>0.39°</td>
<td>0.02°</td>
</tr>
<tr>
<td>&gt;0.96-0.98 ↔ &gt;0.94-0.96</td>
<td>0.23°</td>
<td>0.09°</td>
</tr>
</tbody>
</table>

° C.V.O, *G.M.

Figure 5 plots the number of FP along with their score. Both observers assigned more FP to the Fuji processed images than to the Agfa processed images: C.V.O. assigned in total 1.13 x more FP and G.M. assigned in total 1.38x more FP to Fuji than to Agfa processing.

Figure 5: Number of FP along their scores for both observers
IV. Discussion and conclusion

In this study, 2 processing algorithms have been compared using clinical images that include simulated micro calcifications. The main advantage of this approach is that the exact number of micro calcifications is well-known. In addition, the inserts are fully characterized in terms of x-ray transmission and size in the image plane. This approach leads to quantitative data regarding the detectability of micro calcifications for the two processings. The Fuji processing algorithm had been fine-tuned for mammographic images and is in clinical use. Agfa retrieved its processing from general radiology applications. Our experienced mammographic technologist derived a dedicated set parameters of MUSICA parameters for the particular set of images of this study. Our study shows the superiority of the dedicated processing for detection of micro calcifications in CR images. Perhaps other processing parameters settings might have performed different. Some part of the differences could be attributed to the fact that the images were acquired and readout with the Fuji FCR 5000MA system. In addition the images were printed by using film and printer of Fuji. If we had applied the same procedure to images of other vendors, with different noise and resolution characteristics, other results could have been obtained.

Present results show relatively low detected fractions for most of the micro calcifications. As expected, the detected fractions depend on the size in the image plane and the x-ray transmission coefficients. Both small and relatively large micro calcifications were simulated. In order to situate the clinical relevance of present simulations, we estimated the correspondent Al-equivalent thickness (14) of the studied simulated micro calcifications for the 500-600 µm equivalent diameter group, assuming a compressed breast thickness of 45 mm, exposed at 27 kVp, Mo/Mo. X-ray transmission coefficients between 0.96 and 0.98 correspond to an Al equivalent thickness of more or less 70 µm to 200 µm, the next group from 0.94 to 0.96 corresponds to more or less 200 µm to 400 µm, the group from 0.92 to 0.94
corresponds to more or less 400µm to 600µm and the final group of 0.9 to 0.92 corresponds to more or less 600µm to 800µm.

The strength of our method lays in the choice of artefacts. We could have embedded circular inserts. However, radiologists would recognize these geometric shapes as foreign objects in the mammograms. As a consequence, the threshold contrast visibility could be extremely low. Probably, similar ranking of detection performance for different processings would be obtained. But, the link between these differences and the clinical performance of these processings remains unexplored. As far as we know, no research has been done to compare the detectability of geometric objects with very small size and micro calcifications on mammographic backgrounds. In previous work, we performed a detailed study on the appearance of micro calcifications in terms of x-ray contrast and shape. This guarantees a realistic frequency content of these simulated micro calcifications. The hypothesis of this work was that mammographic images with such simulated lesions are an ideal input for a clinically relevant study of processing algorithms including all the algorithms that adjust the images based on their frequency content. Our study is limited by the fact that we restrict only to the detectability of micro calcifications. We did not include the assessment of the shape of the micro calcifications. In addition, we did not investigate the detectability of other lesion such as masses and general issues such as the global appearance of the breast architecture. The outcome of a comparative study of processing parameters could be different for these items.

Practical difficulties encountered were numerous. This approach requires that clinical input images are available in which the signal intensity is proportional to the detector dose. The retrieval of these images was only possible with the help of a service engineer. The processing of the images with the micro calcifications had to be done manually in a dedicated workstation that was only available in the headquarters of Fuji Benelux. A next problem was the display of these images on standard mammography
workstations in our hospital. The latter problem has larger consequence: in screening organisations that use centralized second reading, compatibility of workstations and mammography systems has to be guaranteed. This is not generally fulfilled at the moment.

V. Appendix

The Fuji image processing combines gradation processing, Multi-objective Frequency Processing (MFP) (5) and Pattern Enhancement Processing for Mammography (PEM) (6). MFP is a type of unsharp masking applied on different frequency bands in the image. The resulting non-linear sum of difference-images is then added to the original image using a contrast dependent enhancement conversion. However, MFP cannot differentiate signals belonging to the same frequency band. Consequently it enhances calcifications, other dotted structures, blood vessels and other high frequency linear structures in the same manner. The PEM process is specially designed for mammography to distinguish between these structures and enhances only low-density isolated dotted shadows such as calcifications. All processing parts are controlled by several parameters which can be adjusted to achieve an image with desired contrast, brightness and edge sharpness.

MUSICA (Multiscale Image Contrast Manipulation) (4), the Agfa processing has been developed for general radiology. It is a multi-scale wavelet-based contrast enhancement technique that involves variable enhancement of various spatial-scale components of the image and additive reconstruction.

VI. Acknowledgment

We would like to thank W. Debondt and J. Vandommele of Fuji for all practical help with the off-line processing printing of the Fuji FCR images. This work was partly sponsored by DIMONDIII, an EC funded research project.
VII. References

(1) The European Protocol for the Quality Control of the physical and technical aspects of mammography screening: Addendum on Digital Mammography, September 2003.


(5) Fuji Computed Radiography, “General Description of Image Processing”.


