

Current and future development: Digital mammography

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Summary

This article reviews the physical aspects, the technical equipment of all available digital systems (a-Si-, a-Se-, CCD-detectors and high resolution luminescence mammography) inclusively CAD (computer-assisted detection resp. diagnose) and all important clinical studies about digital mammography. All aspects will be discussed in contrast to conventional screen film mammography.

Keywords

Digital mammography
Conventional screen film mammography
CAD

Introduction

For many years, almost all types of diagnostic radiology have had digital imaging technology at their disposal, but no adequate digital alternative was available for traditional screen film mammography (SFM) [1-5]. Even in “filmless” hospitals, mammographies were therefore performed in the traditional manner. The reason is that mammography has special requirements vis-à-vis the quality of images, and digital imaging methods are not capable of meeting these requirements just like that. Traditional screen film mammography is thus far the only imaging technique that helped to achieve a reduction in breast cancer mortality when used as a regular screening tool [6]. Its advantages include its comparatively low costs, a high resolution in the high contrast area (up to 20 lp/mm), and easy viewing on a viewbox. In addition to having to find a compromise between definition and exposure, the disadvantage of the imaging system include its low effective quantum efficiency (DQE). Owing to the sigmoid gradation curve of conventional screen film system, each system can be usefully employed only when radiation dosages are clearly defined.

The information conveyed by a radiograph is best described with the so-called signal to noise ratio (SNR). This ratio depends on the radiation dose and the quantum flow that was used to obtain the image, but also on the structural attributes of the imaging system. The DQE is a further important measure to gauge the capacity of a mammography system by indicating how effectively the SNR or the information contained in the radiograph – produced by X-rays that have passed through the chest – is transferred on to the mammogram. The ideal is a transfer ratio of 1:1, i.e. a DQE of 100 %. Real equipment, however, is not capable of such high quality, owing to noise and other processes that reduce the contrast. The resulting quality of the image is therefore always reduced, and the DQE falls to less than 100%. The reduction in the SNR results in an inferior reproduction of small details in the breast, such as microcalcifications. The DQE is dependent on the radiation dose and the local frequency. With the same dose, a system with a high DQE produces images with less noise, or it

produces images of equal quality with a smaller radiation dose than a system with a lower DQE. The DQE enables objective comparison between different radiographical imaging systems on the basis of the image quality and dose efficiency. Currently no standardised procedures exist to help determine the DQE for mammography imaging systems, and especially not for complete mammography workstations with a complete set of components, including images viewers. The DQE values provided by manufacturers of digital mammography systems can therefore not be compared and can be used only as approximate guidelines.

In digital mammography, conventional screen film mammography is replaced by an electronic detector that absorbs the incoming X-rays and produce an electric signal. This signal is digitalised in an analogue-to-digital converter and can be therefore be processed, exposed, and stored on a computer. In conventional film screen mammography, the entire imaging process is linked to the radiograph, whereas in digital radiography, the actual imaging is split into three steps: recording, processing, and reproduction. This means that each individual step can be optimised, and in addition an opportunity arises for electronic image transfer in the sense of tele-radiography. A digital mammogram consists of a finite number of pixels, which are arranged in a two-dimensional image matrix. The distance between two adjacent pixels is known as the sampling frequency or, more generally, as the pixel size. The grey value of each individual pixel is quantified – i.e., represented by a finite number of signals. These values range from 0 to $2^n - 1$, with n equalling the number of bits that are used to digitalise the variation of the analogue signal in the detector. Systems that can be used for mammography capture the data with a depth of up to 16 bit/pixel, equalling $2^{16} = 65536$ shades of grey. The greater the number of pixels and shades of grey, the greater the storage requirement of an individual mammogram.

The digital mammography systems that are currently licensed by the US Food and Drug Administration achieve a resolution of 5-12,5 lp/mm (max) to reach the very high resolution of conventional film screen mammography (of up to 20 lp/mm) digital detectors would have to have a maximum pixel size of 25 μm , which would mean an image matrix of $7200 \times 9600 = 69,1$ million pixels for a detector area for $18 \times 24 \text{ cm}^2$. Nishikawa et al [7], however, found in 1987 that the detection of critical structures is limited more by an SNR that is too low and has too little contrast than by the resolution of the digital imaging system. In spite of this finding, the quality of resolution and its importance in assessing a digital mammography system were the centre of technical discussions for a long time. At a European level work is being done on an addendum to the section covering “digital mammography” in the European protocol for Quality control of the physical and technical aspects of mammography screening (EPOQ), to introduce the threshold contrast visibility as the crucial measure of image quality. The lower requirements vis-à-vis local contrast visibility for digital mammography systems are being justified with the fact that lesions are detected because of their contrast of their background and that contrast visibility or other functions of transmission that use contrast are a more appropriate measure than the modulation transfer function used by film screen systems or the threshold frequency of visual perception that is derived from it [8]. The contrast resolution is determined as the smallest radiological contrast that produces a visible difference in the image for an image detail of a particular size.

Two types of digital mammography systems have to be distinguished: tape-based (offline) and integrated (online) imaging systems. Off-line systems include storage devices (plates, etc) that can be used with any conventional mammography equipment if the exposure variable is selected accordingly. Integrated imaging systems are installed into each individual mammography system and cannot be moved. Further distinction has to be made between full-field systems and scanning systems. Full-field detection are exposed like a film screen system, whereas in the case of scanning systems, an array of detectors is moved very slowly

across the area that is to be imaged, and the X-rays are sent through a slot and therefore limited to the width of the row of detectors.

Digital mammography system with FDA licence

1. Senographe 2000 D (GE Medical Systems, Waukesha, USA)

The digital mammography system Senographe 2000 D by manufacturer GE Medical Systems uses a flat panel digital detector of 19 x 23 cm². The detector is based on a semiconductor layer from amorphous silicium [9, 10, 11] (Table 1).

2. SenoScan (Fischer Imaging, Denver, USA)

The digital mammography system SenoScan by manufacturer Fischer Imaging uses a “slot scan” detector measuring 1 x 22 cm² and consisting of four charge coupled devices (CCDs), using a default pixel size of 54 µm. CCD technology uses a particular attribute of silicium – namely, it converts incoming light photons into mobile charge carriers [9,10,11] (Table 1).

3. PDBI (Hologic/Lorad, Bedford, USA)

The Lorad digital Breast Imager (LDBI) works with a digital image acquisition system, which consists of 12 CCDs that are arranged in the form of a mosaic, and that are coupled with a large scintillator plate that is thallium doped caesium iodide. This receptor covers an area of 18,6 x 24,8 cm². Hologic is, however, not planning further marketing of the CCD-based units but is concentrating its activities on the flat panel digital detector consisting of amorphous selenium [9,10,11] (Table 1).

4. Selenia (Hologic/Lorad, Bedford, USA), Novation (Siemens, Erlangen, Deutschland), digital mammography systems by the Manufactures Agfa, Instrumentarium, Giotto

The digital mammography system uses a 24 x 29 cm² flat panel detector, which, instead of a scintillator, has a semiconductor layer of amorphous selenium. Selenium enables the direct conversion of X-rays into electrical charge [9,10,11] (Table 1).

5. FCR 5000MA (Fujifilm, Tokyo, Japan; Siemens, Erlangen, Deutschland)

Fuji’s full-field mammography system FCR 5000MA includes an image plate reader with a resolution of 50 µm for all mammography formats, with dual-sided reading technology [9, 10, 11] (Table 1).

Results from clinical studies

Ad 1.

Obenauer et al [12, 13] and Fischer et al. [14] compared digital mammography (GE-System] and conventional screen film mammography in clinical and control investigations and found comparable results or slight superiority (not significant) of the digital technique. Grebe et al. [15] and Schulz-Wendtland et al. [16], however, found no significant differences between the two systems. In a comparative study of 692 female patients, Venta, Hendrick et al. [17] found agreement between conventional film screen mammography and digital mammography in 82 %, part-agreement in 14 %, and no agreement in 4 % of results, which they explained this with interobserver variability. Another study by Lewin, Hendrick et al. [18] that included 4.945 female patients found on comparing conventional and digital mammography a total of 35 cases of breast cancer – the conventional system detected 22 cases and the digital system 21 cases. The authors found no significant difference in the detection rate, but a lower recall rate in digital mammography than in conventional mammography (11,5 % v 13,8 %, respectively). They did not find a significant difference in the rate of positive biopsies (19 %

v 30 %). Lewin and Hendrick, in a study in 2002 [19] with 6736 patients whose condition was generally diagnosed through both imaging modalities, found 42 malignancies in 181 biopsies, of which 15 were detected exclusively through conventional mammography and only 9 through digital mammography. They did not find a significant difference in the detection rate for malignancy, but a lower recall rate for digital mammography. The study by Skaane et al. [20] included 1.832 women who were examined with both techniques (additionally generally double reading) (Oslo I). The authors did not find significant differences in the detection rate but a higher rate of air ingress and average parenchymal dose for the digital system than for the conventional system. This study has met with substantial criticism with regard to different variables, and in addition the results are diametrically opposed to those of Hermann et al. [21, 22], who found a dose reduction of 25 % for digital mammography compared with conventional mammography. In 2004 Skaane et al. [23] published a further study (Oslo II) with 10.303 patients examined with conventional and 3.985 patients in digital technique. The detection rate of cancers was 0.54 v 0.83, resp. – the results for the digital mammography were significantly better. Skaane confirmed this with a learning curve of the investigators by working every day with the digital mammography. His conclusion is the necessity of a training (2-3 months) with digital mammography to receive a significant higher accuracy, in contrast to conventional screen film mammography.

Ad 2. and 3.

Studies with small-field detectors, such as the one by Undrill et al. [24] resp. full-field detectors of Schulz-Wendtland [25,26] found, in phantom studies, significantly better results in clarity of detail for the CCD technique as well as film screen mammography and digital systems with a-Se resp. a-Si detector, without significant interobserver variability. Pisano et al. [27] found no significant diagnostic differences between CCD and conventional mammography technique – a study with 6 institutions and 8 investigators and the problems of inter- and intraobserver variability well-known.

Ad 4.

Investigations with an amorphous selenium detector (phantom study) resulted in significant better results in clarity of detail for the digital system versus conventional screen film mammography without significant interobserver variability [Schulz-Wendtland et al., 28].

Ad 5.

The available studies, among other by Schulz-Wendtland et al. [29, 30], show equivalence of luminescence radiography and conventional film screen mammography resp. significant better results [31] of high resolution luminescence mammography.

The results of data published of the Digital Mammography Imaging Screening Trial (DMIST) Investigators Group under the guidance of E. Pisano online in the N Engl J Med (16.09.2005) [32] – the only prospective, randomised clinical trial including a total of 49.000 women, all were examined with both techniques (conventional screen film mammography and digital systems of different manufacturers) separately evaluated in 11 institutions were: same detection rate of cancer for all patients with significant better results for the digital mammography systems at women under 50 years, radiologically dense breasts and pre- resp. perimenopausal women.

Soft copy Reading

Soft copy Reading is possible with the same results like hard copy reading – basis are the European Guidelines for Quality Assurance in Mammography Screening (EPOQ) [8].

CAD

CAD is the computer-assisted detection resp. diagnose in mammography. The whole process is imagine acquisition, segmentation, post-processing and detection. There are existing the following systems: ImageChecker M 1000 (R2-Technology), Second Look (CADx Medical Systems), Mammex TR (Scanis Inc.) and iCad (Fischer) (Table 2). The problem for all systems is the reading of mammograms secondary digitalized. In literature the detection rate of microcalcifications is 86-100% [33-35], for lesions we have sensitivities of 67-89% [35-36], spiculated lesions detection rates of 100% [37]. In double reading CAD systems let increase the sensitivity by the investigators of up to 20% [38]. Karssemeijer et al. [39] published that the investigators with experiences in mammography will have a profit in the diagnostic accuracy with CAD in contrast to the investigator with less experiences: the sensitivity increases, the specificity decreases. In addition the interobserver variabilität has to be considered: 15-90% [38, 40] and of course the problem with CAD systems with the high number of false-positive markers up to 95% [35, 41].

Discussion

The literature overview shows that few clinical studies to date have compared conventional and digital mammography. Tendentially, on the basis of phantom and clinical studies, luminescence radiography with high resolution imaging plates (CR-M) (Fuji/Siemens), digital full-field mammography (GE) (using a digital amorphous silicium detector), digital full-field mammography (Fischer) (digital CCD-detector) and the digital full-field mammography (Lorad, Siemens, Agfa, Instrumentarium, Giotto) (digital amorphous selenium detector) has been found to be of equal value or slightly superior to conventional film screen system [12-32] (Fig. 1-3).

This will be demonstrated by the study of E. Pisano, published 16.09.2005 (N Engl. J Med) [32].

Notably, however both digital mammography devices manufactured by Lorad (detector from amorphous selenium and CCD basis), the digital full-field mammography system manufactured by Fischer (digital CCD-detector), the device manufactured by General Electric (digital amorphous silicium detector), the digital unit by Siemens, Agfa, Instrumentarium, Giotto (digital amorphous selenium detector) and digital mammography with high resolution luminescence (Fuji, Siemens) have been licensed by US FDA (United States Food and Drug Administration).

The future will be digital mammography in combination with CAD and the possibilities of tomosynthesis, contrast-enhanced and dual-energy [42-44] (Fig. 4,5). These are the preconditions for an integration in a PACS (Picture Archiving and Communication System)-system.

Expert commentary

The new strategy in the diagnosis of breast cancer will be the digital mammography. Not only in clinical aspects, especially in mammography screening projects. The visibility and largeness of microcalcifications (pre-invasive cancer) with the help of electronical zooming will improve the diagnosis with the advantage of only small surgical interventions. The result will become a decrease in breast cancer mortality rate.

Five-year view

The world of mammography will be digital with all possibilities of CAD (Computer Assisted Detection/Diagnose), post-processing, tomosynthesis, contrast-enhanced imaging, archiving and teleradiography – all integrated in a PACS (Picture Archiving and Communication System)-system, available for everybody. This will improve the work-flow and the power in a breast cancer center (radiologist, surgeon, gynaecologist, pathologist, radiotherapist) for the best care for the patients.

Key issues

- The basis for digital mammography is the EPOQ (European Protocol for Quality Control)
- Equipment with a-Si-, a-Se-, CCD-detectors and high resolution luminescence have been licensed by US FDA (United States Food and Drug Administration).
- For digital mammography we have equal or better results in the diagnosis of microcalcifications and lesions in contrast to conventional screen film mammography especially at women under 50 years, radiological dense breasts and pre-resp. perimenopausal women.
- CAD (Computer Assisted Detection/Diagnose) , tomosynthesis and contrast-enhanced digital mammography are tools for better diagnosis in future.

Table 1: Digital mammography systems

	Senographe 2000D	SenoScan	LDBI	Selenia / Novation	FCR 5000MA
Manufacturer	GE Medical Systems	Fischer Imaging	Hologic/Lorad	Hologic/Lorad;	Fujifilm
Conversion Material	Szintillator CsI:Tl	Szintillator CsI:Tl	Scintillator CsI:Tl	Photoconductor aSe	Phosphor Storage Screen
Detector Material	ASi	4 CCD (slot detector)	12 CCD (mosaik detector)	aSi	
Pixel Size	100 µm	50 µm	40 µm	70 µm	50 µm (Laser Width)
Field of view	19 cm x 23 cm ²	21 cm x 29 cm ² (scan system)	19 cm x 25 cm ²	24 cm x 29 cm ²	24 x 30 cm ²
DQE	42	50	55	65	45
Spatial Resolution¹	5 lp/mm	10 lp/mm	12,5 lp/mm	7,1 lp/mm	10 Lp/mm
Memory Depth	14 Bit	12 Bit	14 Bit	12 Bit	10 Bit
FDA Approval	January 2000	September 2001	March 2002	October 2002	2004

¹ The designated spatial resolution is the resulting Nyquist frequency from the given pixel size.

Table 2: CAD-System

	Imaging Checkers	Second Look	Mammex TR	iCad
Manufacturer	R2-Technology	CADx medical Systems	Scanis Inc.	Fischer Imaging
Resolution	50 µm	43,5 µm	no comments	no comments
Time of post-processing (4 films)	6-8 minutes	6 minutes	no comments	no comments
Evaluation	Special Alternator every Viewing Station; Monitor	every Viewing Station	every Viewing Station	every Viewing Station
Result	PC-Monitor	Paper	PC-Monitor/Paper	PC-Monitor
Adaptation to Full-Field Digital Mammography Systems	Yes	Yes	Yes	planned

FDA Approval	1998	2002	No	No
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References

Papers of special note have been highlighted as:

* of interest

** of considerable interest

1. BICK, U.:
Digitale Vollfeldmammographie.
RöFo 2000; 173: 957-964.
2. GRABBE, E., FISCHER, U., FUNKE, M., HERMANN, K.P., OBENAUER, S.,
BAUM, F.:
Wert und Bedeutung der digitalen Vollfeldmammographie im Rahmen eines
Mammographie – Screenings.
Radiologe 2001; 41: 359-365.
3. HERMANN, K.P., FUNKE, M., GRABBE, E.:
Physikalisch-technische Aspekte der digitalen Mammographie.
Radiologe 2002; 42: 256-260.
4. SÄBEL, M., AICHINGER, U., SCHULZ-WENDTLAND, R., BAUTZ, W. :
Digitale Vollfeld-Mammographie: Physikalische Grundlagen und klinische Aspekte.
Röntgenpraxis 1999; 52: 171-177.
5. FEIG, S.A., YAFFE, M.J.:
Digital Mammography.
Radio Graphics 1998; 18: 893-901.
6. SCHREER, I.:
Auswertung der bisherigen Mammographie – Screening – Studien in Europa und in
Nordamerika.
Radiologe 2001; 41: 344-351.
7. NISHIKAWA, R.M., MAWDSLEY, G.E., FENSTER, A., YAFFE, M.J.:
Scanned projection digital mammography.
Med Phys 1987; 14: 717-727.
8. European Commission. (2001) European guidelines for quality assurance in
mammography screening, 3 rd. ed. Office for Official Publications of the European
Communities, Luxemburg.
9. BUSCH, H.P.:
Digitale Projektionsradiographie. Technische Grundlagen, Abbildungseigenschaften und
Anwendungsmöglichkeiten.
Radiologe 1999; 39: 710 -724.
10. NEITZEL, U.:
Systeme für die digitale Bildgebung. In: Ewen K (Hrsg) Moderne Bildgebung.

Thieme 2003, Stuttgart, S 127-136.

11. SCHULZ, R.F.:
Digitale Vollfeld – Mammographie: Physikalische Grundlagen und klinische Aspekte.
Fortschr Röntgenstr 2001; 173: 1137-1146.
12. OBENAUER, S., HERMANN, K.P., SCHORN, C., FUNKE, M., FISCHER, U., GRABBE, E.:
Digitale Vollfeldmammographie: Phantomstudie zur Detektion von Mikrokalk.
RöFo 2000; 172: 646-650.
13. OBENAUER, S., HERMANN, K.P., SCHORN, C., FISCHER, U., GRABBE, E.:
Digitale Vollfeldmammographie: Dosisabhängige Detektion von simulierten Herdbefunden und Mikrokalkifikationen.
RöFo 2000; 172: 1052-1056.
14. FISCHER, U., BAUM, F., OBENAUER, S., LUFTNER-NAGEL, S., VON HEYDEN, D., VOSSHENRICH, R., GRABBE, E.:
Comparative study in patients with microcalcifications: full – field digital mammography vs. screen-film mammography.
Eur Radiol 2002; 12: 2679-2683.
15. GREBE, S., DIECKMANN, F., BICK, U., PAEPKE, S., WINZER, K.J., HAMM, B.:
Initial clinical experiences with digital full-field mammography.
Zentralbl Gynäkol 2000; 122, 589-594.
16. SCHULZ-WENDTLAND, R., AICHINGER, U., LELL, U., KUCHAR, I., TARTSCH, M., BAUTZ, W.:
Erfahrungen mit Phantommessungen an verschiedenen Mammographiesystemen.
RöFo 2002; 174: 1243-1246
17. VENTA, L.A., HENDRICK, R.E., ADLER, Y.T., DE LEON, P., MENGONI, P.M., SCHARL, A.M., COMSTOCK, C.E., HANSEN, L., KAY, N., COVELER, A., CUTTER, G.:
Rates and causes of disagreement in interpretation of full-field digital mammography and film-screen mammography in a diagnostic setting.
AJR 2001; 176: 1241-1248.
- * 18. LEWIN, J.M., HENDRICK, R.E., D'ORSI, C.J., ISAACS, P.K., MOSS, L.J., KARELLAS, A., SISNEY, G.A., KUNI, C.C., CUTTER, G.R.:
Comparison of full-field digital mammography with screen-film mammography for cancer detection: results of 4.945 paired examinations.
Radiology 2001; 218: 873-880.
19. LEWIN, J.M., D'ORSI, C.J., HENDRICK, R.E., MOSS, L.J., ISAACS, P.K., KARELLAS, A., CUTTER, G.R.:
Clinical comparison of full-field digital mammography and screen-film mammography for detection of breast cancer.
AJR 2002; 179(3): 671-677.
- * 20. SKAANE, P., YOUNG, K., SKJENNALD, A.:

Population-based mammography screening: comparison of screen-film and full-field digital mammography with soft-copy reading--Oslo I study.
Radiology 2003; 229: 877-884.

21. HERMANN, K.P., OBENAUER, S., GRABBE, E.:
Die Strahlenexposition bei der digitalen Vollfeldmammographie mit einem Flachdetektor aus amorphem Silizium im Vergleich zur konventionellen Film-Folien-Mammographie.
RöFo 2000; 172: 1052-1056.
22. HERMANN, K.P., OBENAUER, S., MARTEN, K., KEHBEL, S., FISCHER, U., GRABBE, E.:
Mittlere Parenchymdosis bei der digitalen Vollfeldmammographie mit einem Detektor aus amorphem Silizium – Klinische Ergebnisse.
RöFo 2002; 174: 696-699.
- ** 23. SKAANE, P., SKJENNALD, A.:
Screen-Film Mammography versus Full-Field Digital Mammography with Soft-Copy Reading: Randomized Trial in a Population-based Screening Program – The Oslo II Study.
Radiology 2004; 232: 197-204.
24. UNDRILL, P.E., O'KANE, A.D., GILLBERT, F.J.:
A comparison of digital and screen-film mammography using quality control phantoms.
Clin Radiol 2000; 55: 782-790.
25. SCHULZ-WENDTLAND, R., LELL, M., WENKEL, E., AICHINGER, U., IMHOFF, K., BAUTZ, W.:
Experimental investigations at the new digital mammography system.
RöFo 2003; 175: 1564-1566.
26. SCHULZ-WENDTLAND, R., HERMANN, K.-P., LELL, M., BÖHNER, C., WENKEL, E., IMHOFF, K., SCHMID, A., KRUG, B., BAUTZ, W.:
Phantomstudie zur Detektion simulierter Läsionen an fünf verschiedenen digitalen und einem konventionellen Mammographiesystem.
RöFo 2004; 176: 1127-1132.
27. COLE, E., PISANO, E., BROWN, M., KUZMIAK, C., BRAEUNING, P., KIM, H., JONG, R., WALSH, R.:
Diagnostic accuracy of Fischer Senoscan Digital Mammography versus screen-film mammography in a diagnostic mammography population.
Academic Radiology; 2004; 11 (8): 879-886.
28. SCHULZ-WENDTLAND, R., WENKE, E., SCHMID, A., IMHOFF, K., BAUTZ, W.:
Experimental investigations of image quality in X-ray mammography with a conventional screen film system (SFS) and a new full-field digital mammography unit (DR) with a-Se-detector.
RöFo 2003; 175: 766-768
29. SCHULZ-WENDTLAND, R., AICHINGER, U., SÄBEL, M., BÖHNER, C., DOBRITZ ,

- M., BAUTZ, W.:
Experimentelle Untersuchungen zur Bildgüte konventioneller Film-Folien-Mammographie, digitaler Mammographie mit Speicherfolien in Vergrößerungstechnik und voll digitaler Mammographie in CCD-Technik.
RöFo 2000; 172: 965-968.
30. SCHULZ-WENDTLAND, R., AICHINGER, U., SÄBEL, M., BÖHNER, C., DOBRITZ, M., WENKEL, E., BAUTZ, W.:
Experimental investigations of image quality in X-ray mammography with conventional screen film system (SFS), digital phosphor storage plate in / without magnification technique (CR) and digital CCD-technique (CCD).
Röntgenpraxis 2002; 54: 53-55.
31. IDEGUCHI, T., HIGASHIDA, Y., KAWAJI, Y., SASAKI, M., ZAIZEN, M. ET AL. :
New CR system with pixel size of 50 micron for digital mammography : physical imaging properties and detection of subtle micocalcifications.
Radiat Med 2004; 22(4) 218-224.
- ** 32. PISANO, E.D., GATSONIS, C., HENDRICK, E., YAFFE, M.J. et al.:
Diagnostic Performance of Digital versus Film Mammography for Breast - Cancer Screening.
N Engl J Med 10.1056/NEJMoa052911
33. BIRDWELL, R.L., IKEDA, D.M., O SHAUGHNESSY, K.F., SICKLES, E.A.:
Mammographic characteristics of 115 missed cancers later detected with screening Mammography and the potential utility of computer-aided detection.
Radiology 2001; 219:192-202.
34. FUNOVICS, M., SCHAMP,S., HELBICH,T.H., LACKNER,B.,
WUNDERBALDINGER, P., FUCHSJÄGER, B., LECHNER,G., WOLF, G.:
Evaluierung eines computerassistierten Diagnosesystems in der Erkennung des Mammakarzinoms.
RöFo 2001; 173: 218-223.
35. FREER, T.W., ULLSSEY, M.J.:
Screening mammography with computer-aided detection: prospective study of 12.860 patients in a community breast center.
Radiology 2001; 220: 781-786.
36. MALICH, A., MARX,C., FACIUS, M., BOEHM, T., FLECK, M., KAISER, W.A.:
Tumour detection rate of a new commercially available computer-aided detection system.
EUR 2001; 11: 2454-2459.
37. KEGELMEYER, W.P., PRUDEDA, J.M., BOURLAND, P.D., HILLIS, A.,
RIGGS, M.W., NIPPER, M.L.:
Computer-aided mammographic screening for speculated lesions.
Radiology 1994; 191: 331-337.
38. JIANG, Y., NISHIKAWA, R.M., SCHMIDT, R.A., TOLEDANO, A.Y., DOI, K.:

Potential of computer-aided diagnose to reduce variability in radiologists
Interpretations of mammograms depicting microcalcifications.
Radiology 2001; 220: 787-794.

39. KARSSEMEIJER, N., OTTEN, J.D., VERBEEK, A.L., GROENWAND, J.H.,
DE KONNING, H.J., HENDRIKS, J.H., HOLLAND, R.:
Computer-aided detection versus independent double reading of masses in mammograms.
Radiology 2003; 227: 192-200.
40. KARSSEMEIJER, N.:
Computer-aided detection and interpretation in
mammography.
In: Yaffe M.J. (ed.) Digital Mammography IWDM 2000. Medical Physics Publishing,
Wisconsin, pp. 243-252.
41. BICK, U.:
Computerassistierte Diagnose in der Screeningmammographie.
Radiologe 1996; 36: 72-80.
42. NIKLASON, L.T., CHRISTIAN, B.T., NIKLASON, L.E., KOPANS, D.B. ET AL.:
Digital tomosynthesis in breast imaging.
Radiology 1997; 205: 399-406.
43. JONG, R.H., YAFFE, M.J. ET AL.
Contrast-enhanced digital Mammography: initial clinical experience.
Radiology 2003; 228: 842-850.
44. LEWIN, J.M., ISAACS, P.K., VANCE, V., LARKE, F.J.:
Dual-Energy contrast-enhanced Digital Subtraction Mammography.
Radiology 2003; 205: 399-406.

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