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Mammographic Artifacts on Full-Field Digital Mammography

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Abstract This study investigates the incidence of full-field digital mammographic (FFDM) artifacts with three systems at two institutions and compares the artifacts between two detector types and two grid types. A total of 4,440 direct and 4,142 indirect FFDM images were reviewed by two radiologists, and artifacts were classified as patient related, hardware related, and software processing. The overall incidence of FFDM artifacts was 3.4 % (292/8,582). Patient related artifacts (motion artifacts and skin line artifacts) were the most commonly detected types (1.7 %). Underexposure among hardware related artifacts and high-density artifacts among software processing artifacts also were common (0.7 and 0.5 %, respectively). These artifacts, specific to digital mammography, were more common with the direct detector type and the crossed air grid type than with the indirect type and linear grid type ($p<0.05$). The most common mammographic artifacts on FFDM were patient related, which might be controlled by the instruction of a patient and technologist. Underexposure and high-density artifacts were more common with direct detector and crossed air type of grid.

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Introduction

Full-field digital mammography (FFDM) with new flat panel detectors, owing to its high quantum efficiency, high resolution, lower radiation dose, and superior image quality, has come to be preferred over screen-film mammography. FFDM differs from screen-film mammography in the ways it acquires, processes, and displays images; artifacts resulting from problems involving any of these components, accordingly, differ from those encountered in screen-film mammography [1]. Digital mammographic artifacts, because they reduce the quality of mammograms and can both create pseudolesions and obscure true lesions, represent a serious quality assurance concern [1, 2]. However, many radiologists and technologists are unfamiliar with them. A significant number of artifacts, particularly those due to software processing errors or detector deficiencies, are unique to digital mammography. Additional artifacts can be incurred by certain detector types [1, 2]. Understanding FFDM artifacts and their classifications according to causes is essential if radiologists and technologists are to correct them in effectively monitoring and maintaining image quality.

To date, there have been only several studies on FFDM artifacts [1–5], among which none has focused on artifact incidence. The goal of the present study was to investigate the incidence of FFDM artifacts classified as patient-related, hardware-related, and software processing artifacts and to compare them according to their detector types and grid types.

Table 1 FFDM equipment and mammographic specifications

Manufacturer	Siemens	Hologic	General electric
System	MAMMOMAT inspiration	Lorad M3 mammography unit	Senographe 2000D
Detector type	Direct flat panel	Direct flat panel	Indirect flat panel
Detector material	Amorphous selenium	Amorphous selenium	Cesium iodide doped with thallium
Anode	Molybdenum and tungsten	Molybdenum and tungsten	Molybdenum and molybdenum
Filter	Molybdenum and rhodium	Molybdenum and tungsten	Molybdenum
Focal spot size	0.1/0.3 mm	0.1/0.3 mm	
Focus-film distance (cm)	65	66	60
Imaging area	24×30 cm	24×29 cm	19×23 cm
Pixel size (μ)	85	70	100
Grid	Linear	Crossed air grid	Linear

FFDM full-field digital mammography

Materials and Methods

Patients

The institutional review board and ethics committee approved the study protocol. A total of 8,582 mammographic images from 2,200 patients underwent screening and diagnostic mammography with FFDM from November 2011 to March 2012; of those images, 4,440 were processed by direct type FFDM and 4,142 by indirect FFDM. Included were bilateral mammography (n =1,962 patients), unilateral mammography (n =181 patients), both implant mammography (n =6 patients), lateral 90° view (n =7 patients), as well as spot compression and magnification view images (n =44 patients). Excluded from the review were specimen mammography, mammography performed on stereotactic biopsy, along with calcification preoperative and localization.

The patients' ages ranged from 27 to 81 years (mean, 53 years).

Mammography Systems

Three FFDM units' parameters are summarized in Table 1. One institution used two direct type FFDM units (MAMMOMAT Inspiration, Siemens; Lorad M3 mammography unit, Hologic), and another institution used one indirect type FFDM unit (Senographe 2000D, GE). Three FFDM units are divided according to grid type into the linear type (MAMMOMAT Inspiration, Siemens; Senographe 2000D, GE) and the crossed air grid type (Lorad M3 mammography unit, Hologic).

Evaluation

All of the consecutive mammograms taken for 4 months were randomly and retrospectively evaluated and radiologists did not know the vendor of FFDM. All visible artifacts were collected according to the consensus of two radiologists with either 6 or 8 years of experience in breast imaging including FFDM. And these were divided into three categories: patient related, hardware related, and software processing artifacts. The patient related artifacts included motion, skin line, antiperspirant, thin breast, and hair artifacts; the hardware related artifacts included those caused by underexposure, field inhomogeneity, collimator misalignment, grid lines, and vibration; the software processing artifacts were high-density or reflected a loss of edge, a vertical or horizontal processing line, or breast-within-a breast [1].

Table 2 Artifacts of FFDM

Artifact	Incidence (percentage)
Patient-related	*154 (1.7)*
Motion	36 (0.4)
Skin line	116 (1.3)
Hair	2 (0.02)
Antiperspirant, thin breast	0
Hardware-related	*64 (0.7)*
Underexposure	62 (0.7)
Collimator misalignment	2 (0.02)
Field inhomogeneity, grid line, vibration artifact	0
Software processing	*74 (0.8)*
High-density	50 (0.5)
Loss of edge	19 (0.2)
Breast within a breast	2 (0.02)
Processing line	3 (0.03)

Patient related artifacts were the most commonly detected types. Underexposure among hardware related artifacts and high-density artifacts among software processing artifacts also were common.

Data are given as number or number (percentage)

FFDM full-field digital mammography

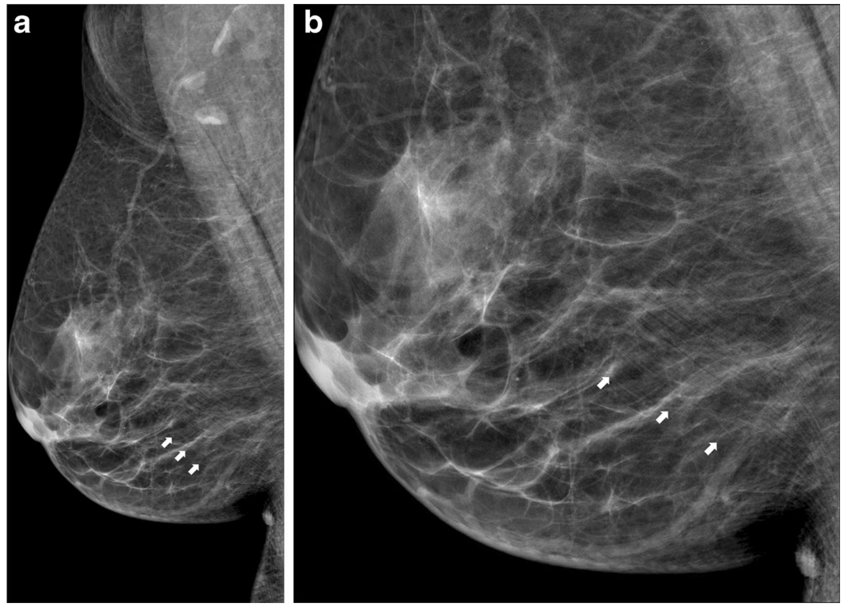

Fig. 1 Skin line artifact on FFDM (indirect type). Right mediolateral oblique (RMLO) mammogram (**a**) shows linear lucent lines (*arrows*) in lower breast. Magnified image (**b**) clearly demonstrates lucent skin lines (*arrows*)

Statistical Analysis

The artifact incidences were calculated. The percentages were compared between the two detector types and the two grid types, respectively, using the chi-square test (MedCalc, version 12, Mariakerke, Belgium). A p value less than 0.05 was considered statistically significant.

Results

The overall incidence of FFDM artifacts was 3.4 % (292/8,582; Table 2). Patient related artifacts were the most common category (1.7 %). The incidences of hardware related and software processing artifacts were 0.7 % (64/8,582) and 0.8 % (74/8,582), respectively. Skin line artifacts were

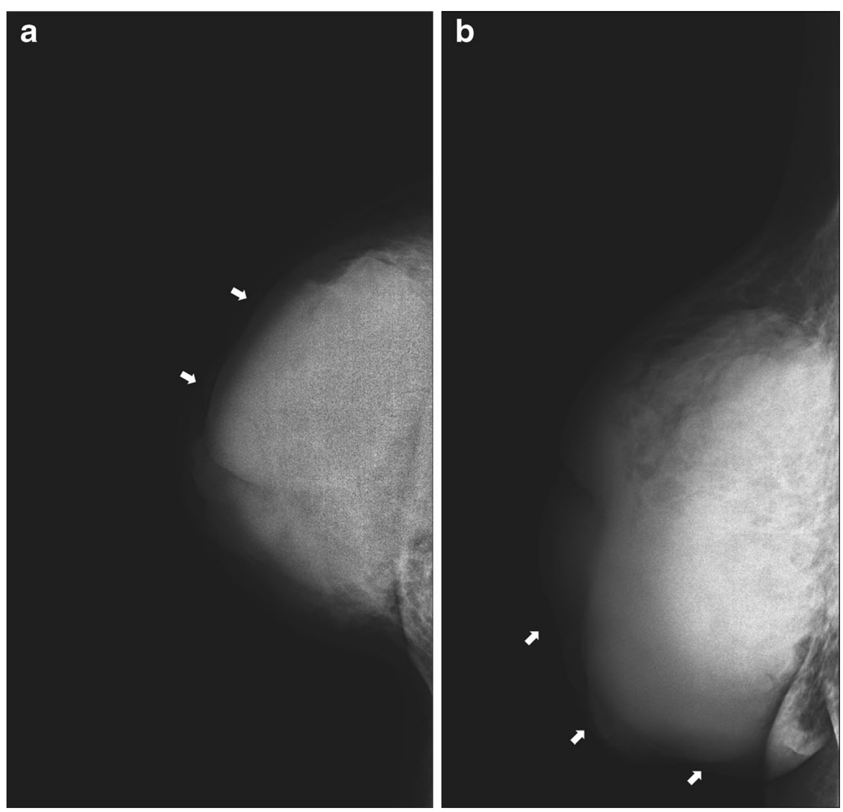

Fig. 2 Underexposure on FFDM (direct type, linear grid type). Right craniocaudal (RCC) (**a**) and RMLO (**b**) mammograms show light regions with dark speckled areas, called as salt-and-pepper effect. There is a breast cancer (*arrows*)

Fig. 3 High density artifact on FFDM (indirect type, linear grid type). Magnified RMLO mammogram shows a high-density chemoport, creating a salt-and-pepper appearance

the most commonly detected (Fig. 1), and underexposure (Fig. 2) and high-density artifacts (Fig. 3) were commonly detected as well (1.3, 0.7, and 0.5 %, respectively).

The incidence of artifacts of the direct-detector type was 4.2 % (183/4,440), and that of the indirect-detector type was 2.6 % (107/4,142; Table 3). The underexposure and high-density artifacts were statistically correlated more with the direct type than with the indirect type ($p<0.05$). Loss of edge was detected only in the direct type ($p<0.0001$; Fig. 4). No significant differences were found for any of the other artifacts.

The incidence of artifacts was 3.2 % (210/6,414) on the linear type grid and 3.7 % (82/2168) on the crossed air type grid (Table 3). High-density and loss of edge artifacts were more frequently detected on the crossed air grid (0.38 vs. 1.15 % and 0.03 vs. 0.78 %, respectively; $p\leq0.0001$). Motion artifacts were more frequently detected on the linear grid type (0.51 vs. 0.13 %, $p=0.028$; Fig. 5). No significant grid type differences were found for the other artifacts.

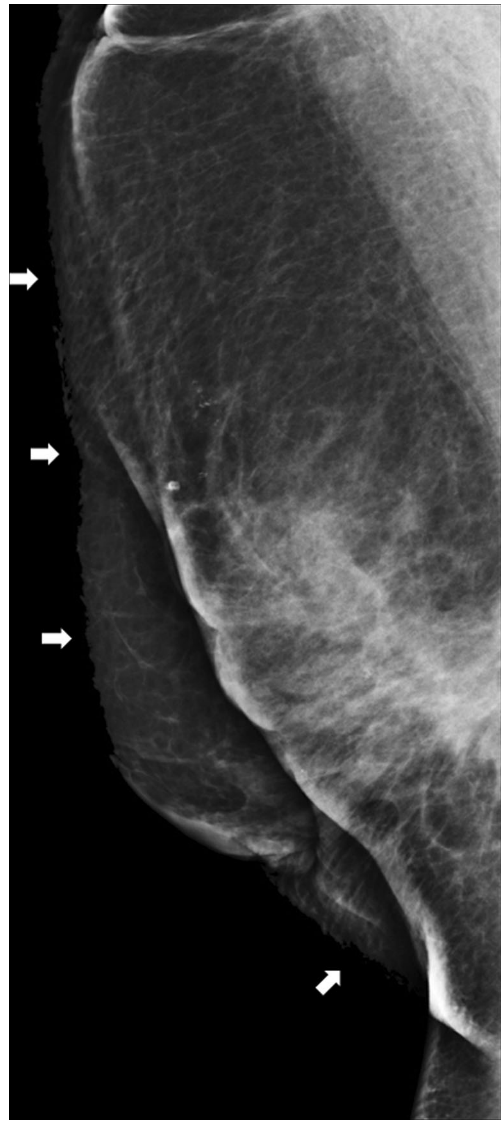

Fig. 4 Loss of edge on FFDM (direct type, crossed air grid type). RMLO mammogram shows loss of edge of the breast (*arrows*)

Table 3 Artifacts according to the detector and grid types

Artifact	Direct ($n=4,440$)	Indirect ($n=4,142$)	p value	Linear ($n=6,414$)	Crossed ($n=2,168$)	p value
Motion	20	16	0.646	33	3	0.028
Skin line	51	65	0.092	96	20	0.059
Hair	2	0	0.172	0	2	0.114
Antiperspirant, thin breast	0	0		0	0	
Underexposure	51	11	<0.0001	49	13	0.506
Collimator misalignment	2	0	0.172	2	0	0.981
Field inhomogeneity, grid line, vibration	0	0		0	0	
High-density	35	15	0.010	25	25	0.0001
Loss of edge	19	0	<0.001	2	17	<0.0001
Breast within a breast	2	0	0.172	0	2	0.114
Processing artifact	3	0	0.094	3	0	0.831

Data are given as number

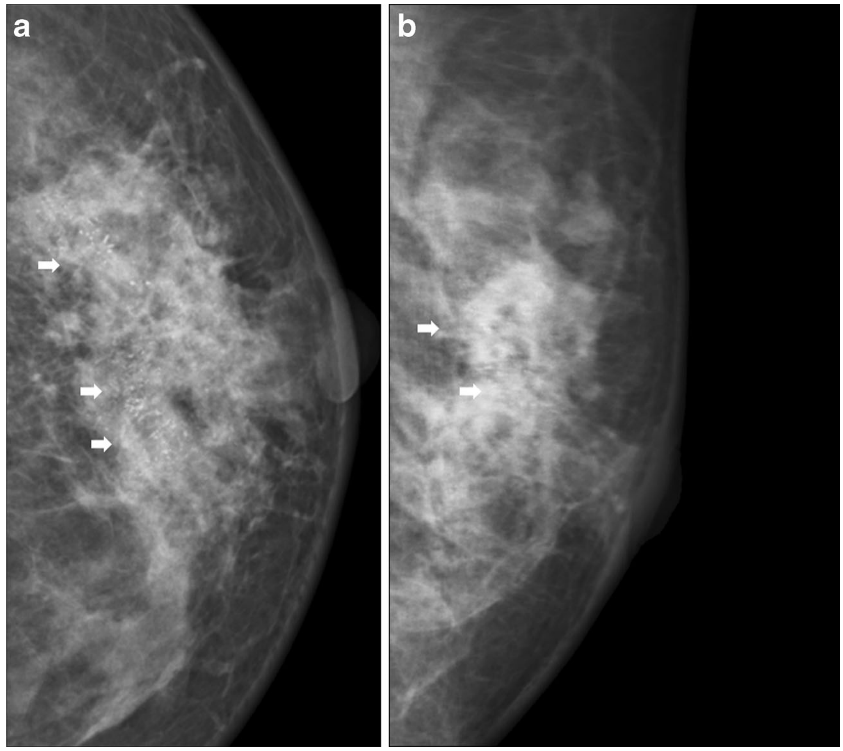

Fig. 5 Motion artifact on FFDM (direct type, linear grid type). LCC mammogram (**a**) shows fine pleomorphic microcalcifications (*arrows*). LMLO mammogram (**b**) shows blurred microcalcifications (*arrows*) due to motion artifact

Discussion

FFDM uses two types of flat panel detectors: indirect and direct. In indirect conversion detectors, a scintillator absorbs the X-ray and generates a light scintillation, which is detected by a photodetector array. In direct conversion detectors, the X-rays are absorbed, and the electrical signals are created, in a single step [1]. Two kinds of scatter-reducing grids also are used: the standard linear grid and the crossed air grid. Standard linear grids effectively reduce scattered photons, but also block some of the primary beam. The crossed air gap is designed to block less of the primary beam, specifically by absorbing scattered radiation in two directions, which results in a better contrast [6].

This study was designed to evaluate FFDM artifact incidence, which was found to be 3.4 %. Artifact incidence, which varies by institution, is evaluated as a part of quality assurance. Only one previous study has examined FFDM artifact incidence: comparing artifacts of screen-film mammography with FFDM. It showed that artifacts occurred in 78 % of screen-film mammography cases, but not at all in FFDM [3]. Crystallization and blooming artifacts, manifesting as blurring of image corners and white dots within a black halo, have been reported for the selenium-based digital mammography detector; these were thought to be detector-hardware related [5]. Ghosting artifacts and the lag effect, meanwhile, have been associated with the flat panel selenium detector [4]. Patient-related and hardware-related artifacts, such as X-ray tube filter defects or grid artifacts, are sometimes seen in both screen-film mammography and digital mammography. Artifacts associated with software processing or detector deficiencies, however, are unique to digital mammography [1]. In the present study, patient related artifacts were the most commonly detected, within which category skin line artifacts predominated. The dynamic range afforded by FFDM makes it far superior to screen-film mammography; this advantage enables, according to a given computer's capability, image display in 16,000 shades of white, gray, and black. Thus, skin line artifacts of wrinkles are much more conspicuous on FFDM than on screen-film mammography. Skin line artifacts, in fact, can produce pseudo-architectural distortions or obscure surrounding structures. Good positioning by the technologist is crucial so as to maintain hand pressure until sufficient compression has been applied to the breast [7].

Underexposure is a unique hardware related artifact that results in a lowered signal-to-noise ratio. This artifact might be acceptable after post-processing, though it can nonetheless obscure small lesions. It has presented as light regions with dark speckled areas, known as "salt-and-pepper." Underexposure is sometimes due to premature aborted exposure or, at other times, to photocell positioning that is improperly close to the edge of the breast. Acquisition with the appropriate exposure parameters can correct this [1, 2]. The incidence of underexposure on the indirect type of FFDM has been reported to be 4 % and on the screen-film system 8 % [3]. In the present study, the incidence of underexposure on the direct and indirect types of FFDM was a significantly lower 0.7 %. Underexposure was markedly lower on the indirect than the direct type ($p < 0.05$), but the number of cases was insufficient for generalization.

The high-density artifact, also known as a pixel dropout, is caused by the effect of spot compression paddle on image-processing algorithms. This high-density artifact, which does not impact the diagnostic interpretation of images [1, 2], was the most common software processing artifact in the present study, showing a 0.5 % incidence. Loss of edge was detected only in the direct type of detector. These two software processing artifacts arose significantly more frequently in the direct detector type and crossed air grid type than the indirect and linear ones, though the number of cases was too small for generalization.

Motion artifacts are associated with patient motion and longer exposure times, and result in image blurring. In the present study, motion artifacts were found more commonly on the linear type of grid than on the crossed air grid. The linear type absorbs less scattered radiation and blocks more of the primary beam compared with the crossed air type and thus requires longer exposure time and higher kilovoltage [6].

Our study has some limitations. First, it was conducted in a retrospective manner and selection bias might be not excluded. Second, the patient-related artifact can be related to technologist (operation) and hardware related artifacts and software processing artifacts can be related to machine (technology). But, we did not include the performance variability of the technologist in this study. Third, three mammographic units from three manufacturers were used at two institutions, and the relevant technologist- and patient-related factors, accordingly, differed. These facts might be problematic as regards any generalization of the present results. Further prospective study, employing and producing larger numbers of mammographic units and mammographic images, respectively, is needed in a prospective manner.

In conclusion, the incidence of FFDM artifacts was 3.4 %. Skin line artifacts were the most common on FFDM; these might be controlled by better informing patients and technologists of their causes. Underexposure among the hardware related artifacts and high-density artifacts among the software processing artifacts were commonly detected and were more common with the direct detector type and crossed air grid type than with the indirect and linear types.

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