Image Quality of Digital Chest X-Rays: Wet Versus Dry Laser Printers

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The aim of this study was to compare the image quality of digital chest x-rays (Thoravision) obtained with 2 "wet" laser imagers of different matrix sizes and a "dry" system. Fifty chest x-rays in 2 planes were printed out in normal (100%) and reduced (61%) format using 3 different systems: 2 "wet" laser imagers (Agfa Matrix LR 3300, 4256 × 5174 pixels, 315 dpi; Agfa Scopix LR 5200, 8512 × 10348 pixels, 630 dpi), and one "dry" system (Agfa Drystar 3000, 4352 × 5295 pixels, 330 dpi). All tests yielded normal findings. Anonymous images were evaluated by 4 independent reviewers on record forms rating the detectability of predefined anatomic structures. When the image quality of diagnosis-relevant, anatomic structures was evaluated on digital chest x-rays reproduced in normal and reduced format, the wet laser imagers did not show significant advantages over the dry system, Agfa Drystar 3000. The Agfa Drystar 3000 system is a feasible alternative for reproducing digital images, particularly for decentralized archives.

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IN BOTH ANALOG and digital projection-based radiography and in digital tomography-based diagnostics (ultrasound, computed tomography, magnetic resonance imaging), film currently is the medium used for documentation and archiving radiologic findings. Although the use of picture archiving and communication systems (PACS) has become more widespread the gray-scale reproduction of digital image records by means of coherent laser beams onto photosensitive films still is common.¹⁻⁴ The recording medium usually consists of a one-sided, argentic transparent film that has to be put through the well-known steps of development,

fixation, wetting, and drying. Stabilization of this film developing process is costly. The chemicals have to be disposed of properly. Therefore, wet chemical procedures only are economically feasible when the documentation is managed in a centralized manner.

The growing use of digitized radiologic imaging procedures has led to an increased demand for technically less complex image documentation systems. This is particularly the case when new imaging devices are installed in decentralized settings or when the number of films to be processed is so small that wet film processing will cause problems as far as preserving the integrity of the developing chemicals.

The first laser imagers based on dry laser-processed film were introduced in 1996.⁵ They offer an alternative to centralized "wet" documentation methods. With dry systems, the film images can be produced at the site at which the examinations are performed.

This study aimed to evaluate if the digital chest x-ray quality (Thoravision; Philips Medical systems, Hamburg, Germany; imaging matrix 2166 × 2488 pixels), achievable by using a dry documentation system, is comparable to the image quality of 2 wet laser imagers with different matrix sizes.

MATERIALS AND METHODS

Patients

In the period between July and December 1999, 50 patients aged between 19 and 78 years (median, 39 years) received clinically indicated chest x-rays in 2 planes with the Thoravision digital imaging system (Philips Medical systems, Hamburg). All patients had a surgically excised malignant melanoma (Clark Level III and IV). All X-rays were taken for cancer follow-up and yielded normal findings. There was not one case of study-related overexposure to radiation.

The chest x-rays in the posteroanterior (PA) and lateral ray were printed out in a standard format (100%) and reduced format (down to 61% original area) on 3 different laser printers after calibration ("wet" laser imagers: Agfa Matrix LR 3300 and Agfa Scopix LR 5200; "dry" documentation system: Agfa Drystar 3000; Table 1).

For reproduction of standard format image records, the image data were expanded from a 2 K imaging matrix to a 4 K and 8 K reproduction matrix, respectively, by means of pixel interpolation. By contrast, when reproducing posterior-anterior (PA)

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Table 1. Reproduction Matrix and Resolution of the Tested Documentation Systems

Documentation System	Reproduction Matrix	Resolution	
Agfa Matrix LR 3300	4256 × 5174	315 dpi	wetsystem
Agfa Scopix LR 5200	8512 × 10348	630 dpi	wetsystem
Agfa Drystar 3000	4352 × 5295	330 dpi	drysystem

and lateral chest x-rays on one film, the image record was reproduced on films at a ratio of 1:1 and 2:1, respectively, ie, no data were lost.

Wet Laser Imagers (Agfa Matrix LR 3300 [LR 3300]; Agfa Scopix LR 5200: [LR 5200])

A laser imager usually can process input signals as analog video signals or as digital image data. The laser beam exposes the film line by line. The beam intensity is determined by the numerical values of the pixels in the corresponding line of the laser camera's memory. It is computer controlled to produce the exact gray scales that are recognizable on the film as density changes, and the intensity is modified by current from the laser diode.

The resolution of a laser camera (pixel size and distance) depends exclusively on the laser beam diameter. Because they have a 50% smaller beam diameter, laser imagers like the LR 5200 have a twice as high resolution compared with conventional laser imagers (eg, LR 3300). The film is plotted with 630 dots per inch (dpi). After the exposure with the laser beam, the method for developing the film in a fixing bath is the same for both wet laser imagers.

Agfa Drystar 3000 (DS 3000)

The DS 3000 dry documentation system uses thermo-sublimation for creating black and white or color half tones. The effect of heat on an ink ribbon transfers the dyes to a film base. A stationary thermal head with individually controlled heating elements reproduces the image on the film as it passes over the head. The amount of dye transferred is proportional to the heat used for each individual pixel. The thermal head contains enough elements that it is possible to achieve a pixel resolution equivalent to "wet" laser imagers.

In compliance with the requirements of ANSI standards (American National Standards Institute), the density loss to be expected within 20 years is a maximum of 10%. Film processing takes an average of 90 seconds, the optical resolution is 320 dpi, and gray-scale depth is 12 bit. The maximum density in the film image is greater than 3.0. The DS 3000 uses films (Drystar) that are not photosensitive but that react to high temperatures and can be processed in daylight.

Digital Selenium Radiography (DSR)

The principle of selenium radiography has been described in detail elsewhere.⁶⁻⁸ The following geometric parameters were used in the examinations: Film-focus distance, 215 cm; maximum image size, 43 × 49 cm; matrix size, 2,166 × 2,488 pixels; pixel size, 0.2 mm. Before starting the study, the de-

vice's image processing algorithms were optimized to the reproduction of chest x-rays. The selected settings were not changed throughout the entire study. The digitized image was printed out on 3 laser printers. This was achieved by consistently adapting the image and reproduction matrix using pixel interpolation to prevent the loss of any information.

Evaluation

All anonymous images of each patient were separated. The resulting 600 images were coded using random numbers and interpreted by 4 independent reviewers (2 specialists in radiologic diagnostics and 2 fifth-year residents in radiology). They read the radiographs according to a questionnaire that rated the image quality of various anatomic structures similar to the criteria of the German Medical Council and the European Commission (Table 2 A and B and 3 A and B).^{9,10} The visibility of critical anatomic structures was measured because, in our opinion, it is essential for diagnostic accuracy of projection radiographic techniques.

For rating the images and the different reproduction formats, images were divided into PA and lateral chest x-rays. A 5-point quality scale was used, which comprised the following items: (1) anatomic structure well visualized in all sections, (2) anatomic structure well visualized in some sections, (3) anatomic structure sufficiently visualized, (4) anatomic structure inadequately visualized, (5) anatomic structure not assessable.

The images were read directly on the viewers' under standardized conditions without any additional illumination lamps. For analysis purposes, the 4 reviewers' ratings were listed for all 6 image records, and each question was itemized and averaged over patients according to image format. The 4 reviewers' mean ratings were averaged for each question relating to image quality. Subsequently, the scores were evaluated by pairs using 2-tailed *t* tests for paired samples. The *P* values produced were interpreted in a purely explorative sense.

RESULTS

Chest Survey X-Rays in the PA Ray (Normal and Reduced Format)

Mediastinal structures. The 2 wet lasers scored virtually the same in the detection of mediastinal structures (number 1-8, Table 2 A and B). There was a tendency toward a better image quality of the wet lasers compared with the dry documentation system, but this difference did not achieve statistical significance.

Pulmonary vessel branches, interstitial pulmonary, and interlobar structures. In evaluating the pulmonary vessels (number 14, Table 2 A and B) and the interstitial pulmonary structures in the retrodiaphragmatic and retrocardiac cavities (number 12 and 13, Table 2 A and B), there was no recognizable difference in the image quality of the laser printers. There were even no differences with regard to the ability to detect the small lobar gap (number 10, Table 2 A and B).

Table 2A. Chest Survey X-Rays in the PA Ray (Normal Format 100%)

Structure	I	II	III	I v II	P Value	I v III	P Value	II v III	P Value
1 Trachea	1.43 (0.30)	1.61 (0.50)	1.60 (0.50)	-0.18 (0.20)	.16	-0.17 (0.24)	.26	0.01 (0.16)	.91
2 Right main bronchus	1.79 (0.47)	1.78 (0.60)	2.06 (0.65)	0.00 (0.28)	.97	-0.27 (0.26)	.13	-0.27 (0.18)	.06
3 Left main bronchus	1.59 (0.45)	1.62 (0.72)	1.86 (0.60)	-0.02 (0.33)	.89	-0.27 (0.30)	.17	-0.25 (0.23)	.13
4 Apical aortic arch	2.26 (0.50)	2.22 (0.62)	2.21 (0.62)	0.04 (0.20)	.75	0.05 (0.23)	.73	0.01 (0.07)	.80
5 Subclavia-heart arch	3.24 (0.67)	3.24 (0.57)	3.18 (0.58)	0.00 (0.11)	1.00	0.06 (0.13)	.47	0.06 (0.13)	.47
6 Paraspinal line	2.62 (0.34)	2.68 (0.61)	2.74 (0.47)	-0.06 (0.80)	.89	-0.13 (0.22)	.34	-0.07 (0.74)	.87
7 Para-aortal line	1.48 (0.26)	1.42 (0.30)	1.54 (0.43)	0.06 (0.37)	.78	-0.06 (0.20)	.59	-0.12 (0.53)	.69
8 Azyg-öso. line	2.74 (0.51)	2.96 (1.16)	2.80 (0.40)	-0.22 (0.92)	.66	-0.06 (0.49)	.84	0.16 (1.34)	.82
9 Spine	3.12 (0.32)	3.20 (0.43)	3.26 (0.61)	-0.08 (0.25)	.56	-0.14 (0.32)	.49	-0.06 (0.47)	.81
10 Minor fissure	2.83 (0.45)	2.65 (0.50)	2.85 (0.44)	0.18 (0.21)	.19	-0.03 (0.03)	.19	-0.21 (0.24)	.18
11 V.azygos	1.82 (0.57)	1.84 (0.71)	1.90 (0.64)	-0.02 (0.34)	.91	-0.08 (0.10)	.20	-0.06 (0.33)	.74
12 Retrocardiac cavity	2.08 (0.16)	2.16 (0.66)	2.19 (0.28)	-0.08 (0.58)	.79	-0.11 (0.29)	.48	-0.03 (0.83)	.94
13 Retrodiaphragmatic cavity	2.99 (0.20)	3.25 (0.57)	3.21 (0.32)	-0.26 (0.43)	.30	-0.22 (0.30)	.24	0.05 (0.70)	.90
14 Pulmonary vessels	1.32 (0.35)	1.36 (0.55)	1.46 (0.45)	-0.04 (0.61)	.91	-0.14 (0.15)	.16	-0.10 (0.58)	.75
15 Ribs	1.90 (0.51)	2.11 (0.44)	2.02 (0.71)	-0.21 (0.65)	.57	-0.12 (0.29)	.47	0.09 (0.90)	.85
16 Soft tissue	1.83 (0.65)	1.73 (0.54)	2.22 (0.80)	0.10 (0.47)	.71	-0.40 (0.41)	.15	-0.49 (0.80)	.31

NOTE. Reviewers ratings averaged for each question relating to image quality, means, mean differences, and standard deviation in parentheses. P value of .05 statistically significant. Laser imager: I = LR 5200; II = LR 3300; III = DS 3000

Visualization of bone and soft tissue. Dry and wet documentation systems were rated equivalent with regard to visualization of the thoracic and abdominal ribs (number 15, Table 2 A and B), the spine (number 9, Table 2 A and B), and axillary and supraclavicular soft tissue (number 16, Table 2 A and B).

Chest X-Rays in the Lateral Ray (Normal and Reduced Format)

Interstitial pulmonary, spinal, and interlobar structures. It proved easier to identify the small

lobar gap with the printer LR 3300 then with the wet laser LR 5200 and the dry system DS 3000 (number 5, Table 3 A).

Concerning the other anatomic structures, when readers' evaluations were analyzed individually, as well as when their evaluations were combined, there was no statistically significant difference in ratings of image quality among all the laser printers, wet or dry.

When reduced-format images were analyzed,

Table 2B. Chest Survey X-Rays in the PA Ray (Reduced Format 61%)

Structure	I	II	III	I v II	P Value	I v III	P Value	II v III	P Value
1 Trachea	1.43 (0.45)	1.65 (0.47)	1.51 (0.53)	-0.22 (0.17)	.08	-0.08 (0.15)	.36	0.14 (0.31)	.44
2 Right main bronchus	1.74 (0.66)	2.08 (0.60)	1.74 (0.48)	-0.34 (0.41)	.20	0.01 (0.23)	.97	0.34 (0.27)	.09
3 Left main bronchus	1.58 (0.67)	1.76 (0.50)	1.63 (0.75)	-0.17 (0.36)	.41	-0.05 (0.25)	.74	0.13 (0.54)	.66
4 Apical aortic arch	2.09 (0.64)	2.13 (0.62)	2.11 (0.55)	-0.04 (0.37)	.84	-0.02 (0.35)	.92	0.02 (0.08)	.64
5 Subclavia-heart arch	2.91 (0.85)	3.36 (0.63)	3.10 (0.71)	-0.45 (0.56)	.21	-0.19 (0.16)	.09	0.26 (0.44)	.33
6 Para-spinal line	2.50 (0.48)	2.93 (0.48)	2.43 (0.68)	-0.43 (0.51)	.19	0.08 (0.34)	.69	0.51 (0.82)	.31
7 Para-aortal line	1.58 (0.36)	1.60 (0.51)	1.39 (0.22)	-0.02 (0.46)	.94	0.19 (0.31)	.31	0.21 (0.51)	.47
8 Azyg-öso. line	3.03 (1.14)	2.46 (0.63)	2.82 (1.14)	0.57 (1.50)	.50	0.22 (0.04)	.01	-0.35 (1.51)	.67
9 Spine	3.20 (0.42)	3.19 (0.60)	3.12 (0.53)	0.01 (0.49)	.97	0.08 (0.18)	.45	0.07 (0.64)	.84
10 Minor fissure	2.87 (0.50)	2.91 (0.48)	3.01 (0.45)	-0.04 (0.05)	.22	-0.15 (0.24)	.32	-0.11 (0.25)	.46
11 V.azygos	1.84 (0.77)	1.96 (0.85)	1.80 (0.71)	-0.12 (0.24)	.39	0.04 (0.11)	.56	0.16 (0.19)	.21
12 Retrocardiac cavity	2.22 (0.32)	2.17 (0.16)	1.90 (0.52)	0.05 (0.44)	.84	0.32 (0.26)	.09	0.26 (0.59)	.44
13 Retrodiaphragmatic cavity	3.22 (0.38)	3.19 (0.30)	3.06 (0.45)	0.04 (0.49)	.90	0.16 (0.27)	.32	0.13 (0.38)	.56
14 Pulmonary vessels	1.59 (0.49)	1.47 (0.48)	1.39 (0.67)	0.12 (0.29)	.48	0.20 (0.33)	.31	0.09 (0.62)	.80
15 Ribs	2.14 (0.20)	2.02 (0.61)	1.98 (0.60)	0.12 (0.46)	.64	0.16 (0.41)	.50	0.03 (0.47)	.89
16 Soft tissue	1.82 (0.64)	2.03 (0.76)	1.65 (0.68)	-0.21 (0.73)	.61	0.17 (0.15)	.11	0.37 (0.79)	.41

NOTE. Reviewers ratings averaged for each question relating to image quality; means, mean differences, and standard deviation in parentheses. P value of .05 statistically significant. Laser imager: I = LR 5200; II = LR 3300; III = DS 3000

Table 3A. Chest Survey X-Rays in the Lateral Ray (Normal Format 100%)

Structure	I	II	III	I v II	P Value	I v III	P Value	II v III	P Value
1 Spine, upper third	2.55 (0.54)	2.65 (0.44)	2.89 (0.88)	-0.10 (0.38)	.64	-0.34 (0.37)	.17	-0.24 (0.68)	.54
2 Spine, mid third	1.74 (0.40)	1.81 (0.43)	2.00 (0.59)	-0.07 (0.35)	.71	-0.26 (0.24)	.13	-0.19 (0.47)	.49
3 Spine, lower third	1.72 (0.39)	1.61 (0.56)	1.95 (0.64)	0.11 (0.53)	.71	-0.24 (0.38)	.30	-0.35 (0.60)	.34
4 Major fissure	2.18 (0.75)	2.04 (0.68)	2.25 (0.79)	0.14 (0.21)	.28	-0.07 (0.12)	.32	-0.21 (0.28)	.23
5 Minor fissure	2.49 (0.70)	2.25 (0.76)	2.44 (0.75)	0.24 (0.14)	.04	0.06 (0.18)	.59	-0.19 (0.08)	.02
6 Retroc. cavity	1.57 (0.57)	1.67 (0.61)	1.83 (0.54)	-0.10 (0.17)	.33	-0.26 (0.46)	.33	-0.17 (0.57)	.60
7 Retrost. cavity	1.92 (0.48)	1.78 (0.35)	2.01 (0.76)	0.13 (0.23)	.32	-0.09 (0.42)	.68	-0.23 (0.64)	.52

NOTE. Reviewers ratings averaged for each question relating to image quality; means, mean differences; and standard deviation in parentheses, *P* value of .05 statistically significant. Laser imager: I = LR 5200; II = LR 3300; III = DS 3000.

the wet laser LR 5200 and the dry system DS 3000 were preferred generally over the LR 3300 wet laser, but the difference did not achieve statistical significance (Table 3B).

DISCUSSION

Currently, besides soft copy documentation on monitors, the most commonly used documentation systems in digital radiology still are laser imagers and silver-halide films that require wet film processing. In the laser camera, the film is exposed by the laser beam pixel by pixel directly via the monitor. The beam intensity is adjusted according to the gray-scale.

So-called dry systems offer an alternative to this method by avoiding wet film development. The term *dry* refers to the various types of reproduction methods in which the film does not have to be washed with photosensitive silver halides.¹¹ In one dry laser imager, the Imation DryView 8700, the film is developed by heating. The system we tested utilizes the principle of thermosublimation for image reproduction.

The main benefits of dry systems is their environmental safety and the resulting lower costs. Because no wet chemicals are used, the time and cost-intensive service and maintenance of the developing machines are eliminated. No installations

for water, waste-water, or exhaust systems are required, and there are no costs for disposing of the byproducts. Large-scale developing machines are an integral part of all wet laser imagers. By contrast, the dry documentation systems are smaller in size, ie, approximately 0.5 m², which means that they can be used anywhere that is therefore more conducive to the organizational process.

Gahleitner et al¹² compared the image quality and film stability of a dry laser (3M/Imation Dry-View 8700) with a wet laser imager (3M/Imation 969 HQ) by evaluating the reproductions of computed tomographic (CT) and magnetic resonance images (MRI). The results of the dry documentation system did not meet the quality standard of the wet laser imagers. Brightness and contrast scored worse in the dry system than with the wet laser. However, the investigators concluded that the diagnostic validity of the images reproduced on the dry laser imager was sufficient to justify the use of the system for CT and MRI examinations and utilized the practical and ecologic advantages. In contrast, Krupinski¹³ found that the image quality achievable with the same dry laser imager was equivalent or better for reading CT, MRI, and ultrasound images than those of a wet laser imager (3M/Imation 969 HQ), but in light of the different requirements for image quality, the findings of

Table 3B. Chest Survey X-Rays in the Lateral Ray (Reduced Format 61%)

Structure	I	II	III	I v II	P Value	I v III	P Value	II v III	P Value
1 Spine, upper third	2.63 (0.26)	2.84 (0.83)	2.69 (0.49)	-0.22 (0.59)	.52	-0.07 (0.31)	.70	0.15 (0.57)	.64
2 Spine, mid third	1.83 (0.32)	1.94 (0.53)	1.84 (0.46)	-0.11 (0.48)	.66	-0.01 (0.20)	.93	0.11 (0.53)	.72
3 Spine, lower third	1.80 (0.43)	1.91 (0.61)	1.74 (0.52)	-0.11 (0.39)	.63	0.07 (0.21)	.59	0.17 (0.55)	.58
4 Major fissure	2.23 (0.82)	2.38 (0.90)	2.16 (0.71)	-0.15 (0.20)	.23	0.07 (0.11)	.31	0.22 (0.27)	.21
5 Minor fissure	2.41 (0.81)	2.71 (0.85)	2.62 (0.55)	-0.31 (0.24)	.08	-0.21 (0.32)	.28	0.10 (0.33)	.61
6 Retroc. cavity	1.70 (0.54)	1.81 (0.53)	1.65 (0.61)	-0.10 (0.56)	.73	0.05 (0.16)	.57	0.16 (0.50)	.58
7 Retrost. cavity	1.98 (0.46)	1.99 (0.64)	1.80 (0.36)	-0.01 (0.37)	.96	0.18 (0.22)	.21	0.19 (0.52)	.52

NOTE. Reviewers ratings averaged for each question relating to image quality; means, mean differences, and standard deviation in parentheses. *P* value of .05 statistically significant. Laser imager: I = LR 5200; II = LR 3300; III = DS 3000.

studies conducted with ultrasound, CT, and MRI are not transferable to projection-based radiographic examinations.³

A study comparing image quality of the dry documentation system DS 3000 with wet laser imagers in the reproduction of digital chest x-rays is not known to the authors.

When readers interpreted chest x-rays in 2 planes, with images reproduced in the normal and reduced format, they found no statistically significant difference in the image quality of diagnostically relevant anatomic structures comparing the DS 3000 with the wet documentation systems.

Compared with reproduction in the standard format with the respective documentation systems, there was no significant difference between individual wet and dry imagers in the image quality of formats reduced to 61% of the initial surface area prescribed by the manufacturer. This was true when the ratings of all reviewers were summarized and when ratings were analyzed individually. This is consistent with the results of an earlier study that used one of the wet laser imagers.¹⁴ To reproduce the images on one film, the digital records were expanded from a 2 K imaging matrix to a 4 K (LR 3300; DS 3000) and 8 K (LR 5200) reproduction matrix by means of linear pixel interpolation. In comparison, the image was reproduced without the

loss of data when 2 selenium images were reproduced on a film at a ratio 1:1 and 2:1.

As expected, the doubled reproduction matrix of the LR 5200 with 8 K provided no noticeable advantages in the 2 K imaging matrix we used compared with the LR 3300 and the DS 3000. New imaging techniques like digital mammography require higher-resolution film documentation compared with the projection-based radiography of the chest. This means that the LR 5200 here might have some conceivable advantages over the other documentation systems.

The limitation of the study might be that only the visibility of anatomic structures was rated, but, in our opinion, from the clinical perspective, a good visibility of critical anatomic structures is the essential basis of diagnostic accuracy in digital chest x-ray. It also has to be pointed out that the results we found only apply to chest images and may not generalize to other types of images.

There were no significant differences in the documentation of selenium radiographic chest x-rays using imaging matrix sizes of 2166×2488 pixels between the individual documentation systems tested with regard to image quality and diagnostic information. Hence, the DS 3000 does represent an alternative to wet lasers, especially when decentralized documentation is required.

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