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High-Resolution Industrial Radiographs: An Introduction

Historical Context

Industrial Film Performance Results

Historical Context

The historical development of radiology has been driven by the need to provide the most accurate diagnosis of the patient's ailment, using the technique that gives the greatest amount of information in order to provide the best prognosis and resulting management plan. Technology suppliers have worked diligently with radiologists to provide better technology to match the improvements made in radiology techniques. This cooperation with radiologists and technologists, working together to help patients, has occurred on virtually a daily basis.

The early radiographic films were very similar to industrial radiographs. They both used small crystals to absorb the direct X-ray exposure to give excellent image quality. A high dose, with manual processing, was used. Companies such as Kodak led the way to develop materials that could reduce the dose.

- **1960s** Kodak developed blue emitting screens to reduce the dose by 50%.
- **1970s** 3M developed green Trimax screens to reduce the dose by another 50%.
- **1980s** Kodak developed T Grain technology for faster automatic processing and higher image quality.
- **1990s** Kodak developed InSIGHT dedicated thoracic films.
- **1990s** With mammography films, there were massive improvements in film structure and emulsion technology to improve dose and image quality.

The original equipment manufacturers (OEMs) made massive strides in new digital technology, improving:

- Computed tomography (CT) scanners
- Magnetic resonance (MR) imaging scanners
- Positron emission tomography (PET) scanners
- Computed radiography
- Digital radiography
- Picture archiving and communication systems (PACS)

This mixture of techniques and technology has benefited numerous patients, leading to successful clinical outcomes. There exist ailments that require a higher X-ray dose to provide sufficient details in the image for a successful diagnosis. Mammography and oncology are examples in which this delicate balance of dose versus image quality is required in order to make the right diagnosis.

Orthopedics is another area where some ailments require very special imaging techniques to be able to make the right diagnosis. This book is dedicated to describing the techniques and applications required for the minority of patients who need very detailed images of the hand for the diagnosis of disease.

Industrial Film Performance Results

Many papers in the radiologic literature have defined how to obtain optimal, high-resolution images of bone structures. Using high-quality, fine phosphor crystals in the analog radiographic screens, coupled with a radiographic film having an intrinsic high contrast, has been recommended. This combination permits the reduction of granularity in the radiographic image, which, if not controlled, would negatively impact any resolution of fine details in the image. This particular type of examination demands an extremely high definition combined with high contrast, which can be achieved by using two different technical solutions:

1. A double-sided film, normally used in industrial applications, containing a high quantity of very fine silver halide crystals with a very narrow distribution profile. This creates, after processing, a high contrast image with a high resolution. The film is directly exposed in its light-safe container, in direct contact with the element being X-rayed.
2. A film/screen combination based on mammography film with its corresponding mammography screen exposed using X-ray techniques more normally seen in dedicated mammography examinations.

The two systems were compared using the following parameters:

- Dose and contrast (measured based on ISO 9236-1)
- Modulation transfer function (MTF) (measured based on ISO 9236-2)

The processing condition optimization study of the two systems was done using a manual and an automatic process. The two systems were evaluated in an automatic process, using a dedicated mammography processor with dedicated mammography processing chemicals, while the manual process was reserved for the X-OMAT industrial film.

Automatic Processing Conditions

- Developer temperature = 34°C
- Total processing time (dry to dry):
  - Min-R EV mammography film = 120 s
  - X-OMAT MA industrial film = 270 s

Manual Processing Conditions

- Developer temperature = 32°C
- Variable treatment time in the processing bath = 3–5 min
- Fixed treatment time in the processing bath = 1 min

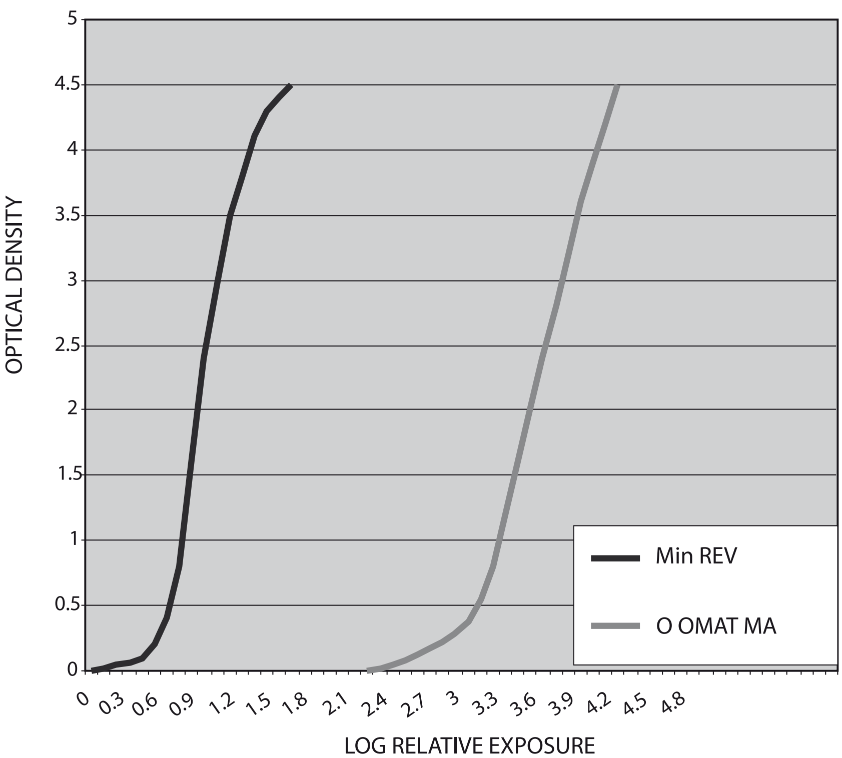

Fig. 1 Sensitometric curve comparison using automatic processing conditions

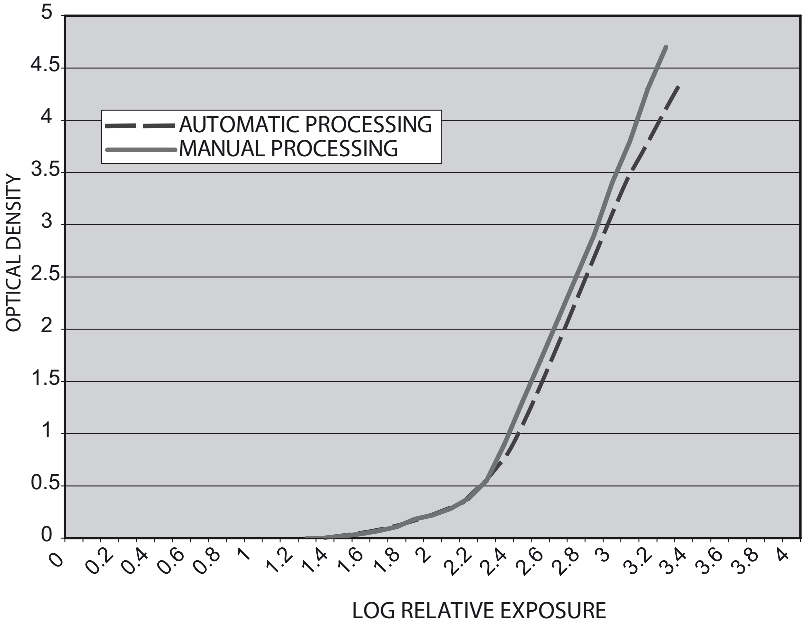

Fig. 2 Sensitometric curve effects of automatic versus manual processing of X-OMAT MA film

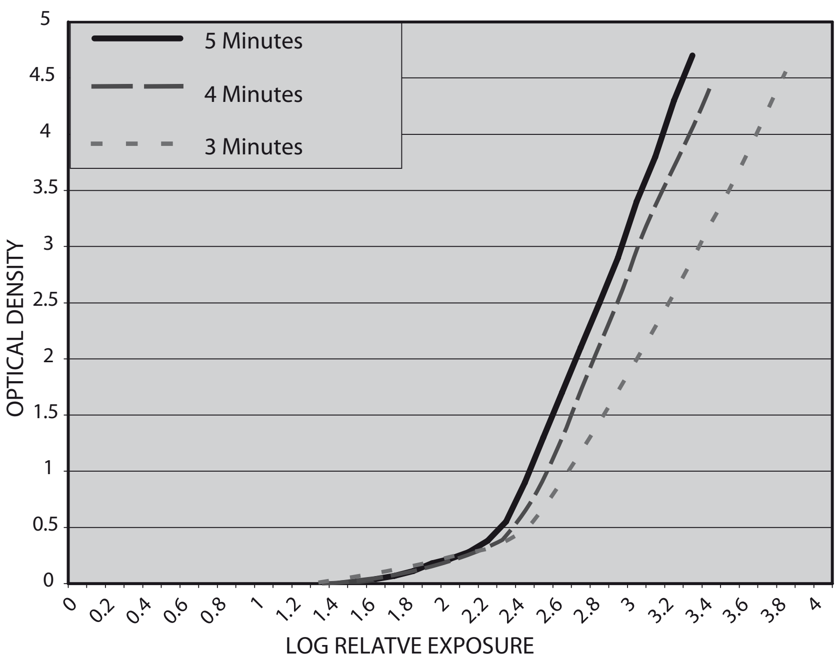

Fig. 3 Sensitometric effect of varying manual processing time of X-OMAT MA film

Interpretation of Results

Figures 1–3 demonstrate that by increasing the manual processing time, the average contrast increases to achieve a maximum of 3.30. There is also a slight increase in sensitivity as the processing lengthens, corresponding to a lower patient dose. In manual processing, the use of a hardener-free developer, such as Kodak LE Plus Developer, is strongly suggested as it permits a more even and rapid development process to be obtained.

Contrast and Dose

The two systems under consideration were exposed using a GE Mammograph SENOGRAPHE DMR and a plastic step-wedge, with 12 steps to validate the dose received at 28 Kv. The following systems were exposed:

1. Kodak X-OMAT MA industrial film / direct exposure
2. Kodak Min-R EV mammography film / Kodak Min EV150 screen

Exposure technique:

- 28 Kv, 160 mA, ddf 60 cm
- 28 Kv, 12 mA, ddf 60 cm

The automatic processing times were varied, based on the chemical and physical characteristics of the two films evaluated. The results indicated significant differences in the speed of the systems and the contrast of the resulting images.

Kodak X-OMAT MA Film

The direct exposure achieved an average contrast value at 3.30 that may be considered as the optimum value to permit the visualization of fine bone structure. A critical parameter is to be able to see dense bone structure that absorbs significant quantities of the X-rays. This is the **toe contrast** value, which in this system has a value of 1.45 that permits very small variations in X-ray absorption to be seen with different gray levels. This results in a greater capability to diagnose details in the area of low optical density in the radiographic image.

Kodak Min-R EV Film / Kodak Mammography EV150 Screen

The film-screen system delivered an average contrast of 4.52, giving significant advantages in the appropriate mammography examinations done with this system, while in the diagnosis of fine bone structure, the extremely high contrast negatively affects the perception of the image by increasing the perception of the granularity of the image. Combined with this, the **toe contrast** gave a value of 2.04, which reduces the ability to perceive small changes in gray levels in the areas of underexposure, predominantly of dense bone structures. One significant advantage of this system is that the patient exposure dose is drastically reduced, compared to the direct exposure system.

Modulation Transfer Function (MTF)

The MTF measurement was based on a target of parallel X-ray-opaque and X-ray-transparent layers. The variable frequency of fine lead strips is the basis of this target. As the frequency of the lead strips increases, the spaces between the maximum density areas decreases (D_{max} areas correspond to strips of X-ray-transparent materials) and the spaces between the strips of minimum density increase (D_{min} areas correspond to strips of lead in the target). The higher frequency corresponds to an increased difficulty in being able to distinguish areas of rapid changes in the light and dark strips.

The study of the MTF helps in defining the ability of the radiographic system to differentiate the smallest anatomic detail with diagnostic confidence. A higher MTF value corresponds to a higher diagnostic quality of the radiographic image. The direct exposure, without using phosphor screens, of X-OMAT MA gave a higher MTF compared to the dedicated mammography system, Min-R EV/EV150, using phosphor screens, which despite having very fine grain X-ray phosphors, compromised the sharpness of the resulting images (Fig. 4).

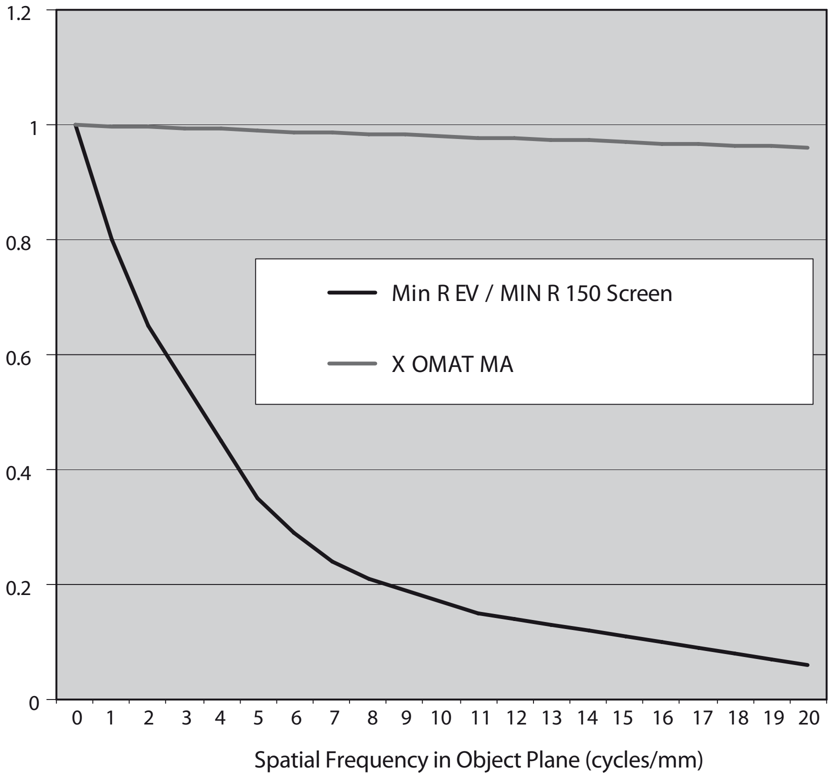

Fig. 4 Modular transfer function comparison of systems

Conclusions

The improvements in digital technology are proving to be of significant benefit to patient care in terms of lower dose and improved manipulation of data for more effective image diagnosis. The work developed here demonstrates clearly that, in the orthopedic assessment of small bone structures, there exists a need for a level of extremely high image quality for very specific ailments, where the dose is a secondary concern. The clarity of details in the image permits an accurate diagnosis and hence permits a relevant patient management plan.

Over the last ten years, digital imaging has made outstanding improvements to patient care. The use of alternative analog techniques, which can still offer considerable patient care, will be superseded by digital imaging in the near future. Today, the crossroads has been reached, such that analog techniques are still part of the weaponry that radiologists can use for the niche cases in which digital imaging has still yet to offer a complete solution.

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