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Integrated digital radiography with a flat electronic detector

New digital techniques improve efficiency in radiology.

Over the last ten to fifteen years, the role of digital acquisition techniques in radiology has steadily increased, albeit somewhat less rapidly than originally anticipated. Nowadays, virtually every radiographic examination can be performed digitally, with a quality at least equal to, if not better than, that of conventional techniques [1].

Nevertheless, in many of the institutions that have already introduced digital acquisition techniques, the working methods have remained essentially conventional. Cassettes are still used, although they now contain storage screens rather than screen-film combinations. The image is still assessed as a (laser) film on a lightbox. In fact, the complete working routine has not changed significantly with respect to the conventional procedures of the past. So far, only a few institutions have made the step to a completely filmless working procedure.

The first signs of change have only appeared very recently. Advances in computer techniques have now made the necessary means available for processing, communication and storage of the large amounts of data involved in radiography, while new digital detectors that allow direct electronic acquisition of the radiographic image are now being discussed in the literature [2, 3].

The expected increase in efficiency, and the associated reduction in costs, are playing an increasingly important role as the driving force behind the digitization of the radiology department.

In this article, a short review of the development of digital radiography to date is followed by a discussion of the importance of the new detector technology for the digital radiology department of the future.

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Computed radiography (storage phosphor screens)

The storage phosphor technology introduced at the beginning of the 1980's has dominated digital radiography to such an extent that, in the English-speaking countries, the term 'computed radiography' is used as a synonym for this technique alone.

The specific advantages of computed radiography, i.e. its greater exposure latitude and the constant image quality, predestined this technique above all for those applications in which precise exposure cannot be guaranteed, such as examinations in bed patients, and in the intensive care unit (Fig. 1). However, digital acquisition with storage screens of the latest (5th) generation is at least as good as acquisition with screen-film combinations in standard examinations on a bucky table [1]. This is also clear from the physical properties: the detection quantum efficiency (DQE) of the storage phosphor screen system has now drawn level with that of the screen-film systems [4].

Fig.1. Lateral bed exposure with storage phosphor screen cassette (Philips PCR).

As a cassette-based system, computed radiography has both advantages and disadvantages with respect to digitization of the radiology

Volume 41 Issue 2
November 1997

department. Due to the compatibility of the technique with the available X-ray stands, the required investment is limited to the special cassettes, the reader system and the image processor. All the X-ray stands can still be used. The familiar working routine can also be maintained, particularly when the diagnosis is made using (laser) film. This avoids the problems of conversion. At the same time, the technique offers full facilities for digital image storage and communication, e. g. with the referring departments.

A disadvantage of computed radiography, however, is that the potential for cost saving is limited. As cassettes still have to be transported between the X-ray examination room and the read-out equipment, it is difficult to achieve any significant increase in the efficiency of the patient examination procedure. The costs of disposables can only be reduced when the images can be reproduced in a smaller format, or when diagnosis can be made from the monitor screen. Nevertheless, computed radiography, supported by integration in a modern radiology information system (RIS) is, and will continue to be, the most suitable path towards the digital future, particularly for the smaller institutions.

Selenium radiography with Thoravision

Dedicated systems for chest examinations continue to play a major role in the radiology department. The high proportion of chest examinations, together with the largely standardized working procedure, have led to the development of special acquisition systems adapted to the high patient throughput. For some years, the Philips Thoravision system for digital chest radiography (Fig. 2) has been available as a successor to the conventional serial changer. The exposure is made on a selenium layer. The stored exposure pattern is scanned, and converted directly into a digital signal. This selenium detector technology has a detective quantum efficiency (DQE) which is about twice as high as that of screen-film systems or storage phosphors, ensuring the highest possible image quality [5, 6, 7].

Equally important for use in clinical practice are the ergonomic advantages that can be achieved by consistent exploitation of the possibilities offered by digital imaging. For example, provision for integration in a RIS is a standard feature in the Thoravision. This means that the data on the patients to be examined can be directly transferred to the Thoravision system as a worklist; information on the examinations carried out can also be reported back to the RIS, so that it is available for billing or other administrative purposes.

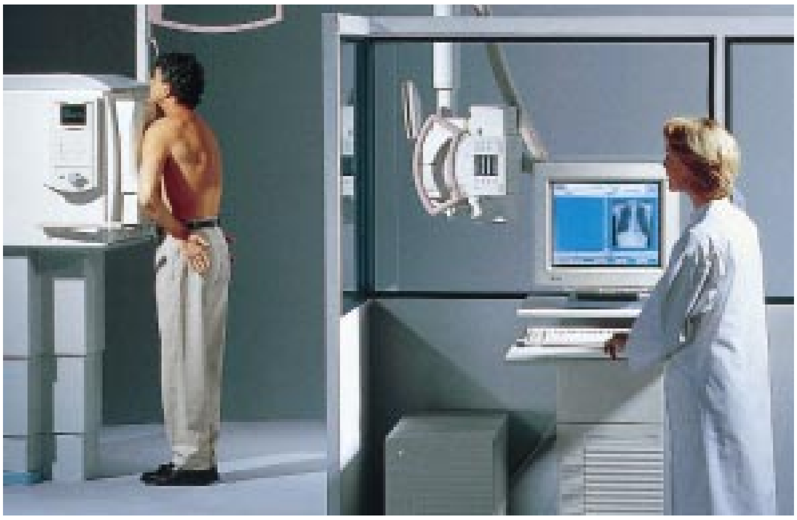


Fig. 2. The Thoravision system for digital chest radiography is fast and easy to use, providing a significant increase in efficiency.

The image is displayed on the monitor immediately after acquisition, so that the image quality can be checked while the patient is still in the examination room. Any changes in the patient position or the diaphragm settings can be made immediately, without having to wait until a film has been developed.

The digital images are automatically combined with the patient and exposure data in the system and transferred on-line to the laser camera or the diagnostic workstation. The radiographer no longer has to transport cassettes or films, making it possible to achieve a significant increase in patient throughput.

Selenium radiography (Thoravision) is the model for fully integrated digital image acquisition.

The Thoravision system can justly be regarded as the model for the fully integrated digital workstations of the future. The system has now been installed in well over 100 radiological institutions all over the world.

Flat electronic detectors

The next step towards digital integration of the classic X-ray acquisition technique is the use of electronic image detectors in bucky systems.

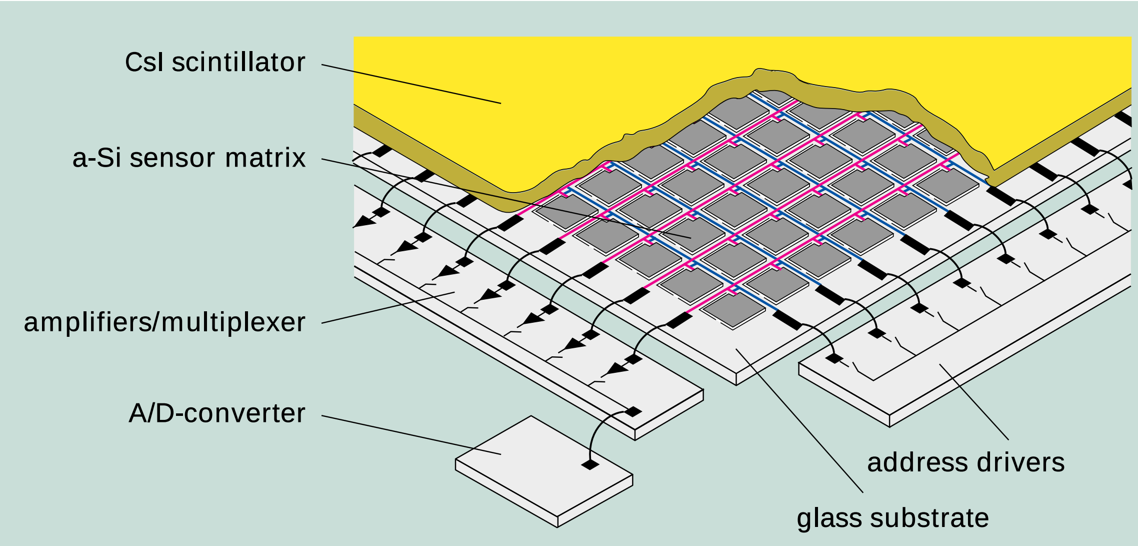
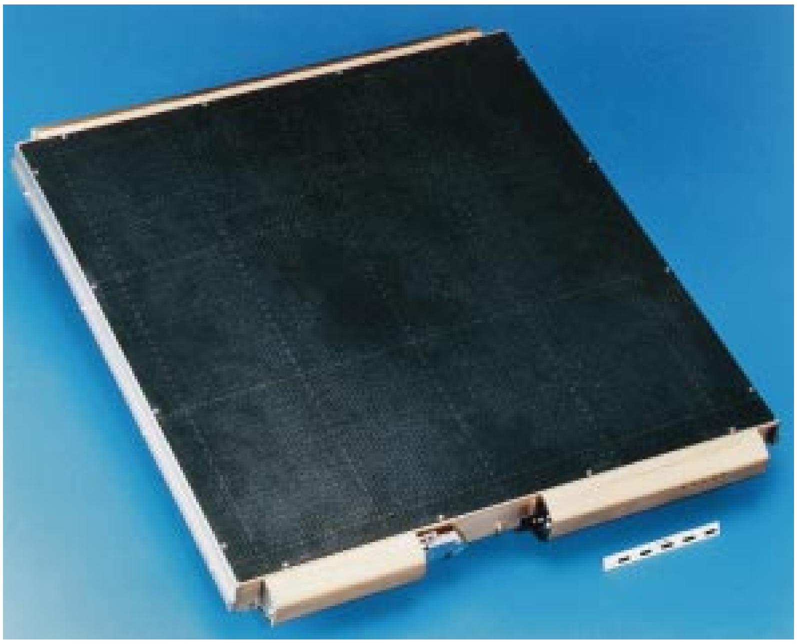


Fig. 3. Construction of the flat silicon detector. The X-ray sensitive converter layer consists of caesium iodide (CsI). The amorphous silicon sensor array comprises 3000 x 3000 pixels.

At present, all the large manufacturers of medical imaging equipment are preparing solutions to this problem. The development is based on new X-ray detectors employing large-area amorphous silicon (a-Si) semiconductor sensors. Details of the technology of this detector system are given in the Intermezzo on page 17. In the Philips Research Laboratories, the components needed for this technology have been intensively studied and optimized over a period of several years [8]. An advantage in this connection was that Philips could draw on the experience obtained in the development of the technically similar flat-screen technology for computer display screens. This made it possible to apply the first 20 x 20 cm X-ray flat panel detector as early as 1995.
It already allowed fluoroscopy to be carried out at 25 images per second.

Fig. 4. Flat detector module for integration in a bucky workstation. Detector format: 43 x 43 cm.



Philips has now brought its know-how, acquired from basic research in this area, into a European consortium that has been set up for industrial production of the detectors. The Trixell company, based in France, will supply the three parent companies Thomson, Siemens and Philips, and, at a later date, other interested parties. This was the only way of amortizing the high investments in development and production, and manufacturing the new flat detectors on a sound commercial basis.

The expected advantages of the new electronic detectors in the digital X-ray acquisition technique are outlined below.

High image quality
As with the selenium detector of the Thoravision system, the flat silicon detector offers a significantly higher DQE than conventional screen-film systems. This results in an excellent signal-to-noise ratio and, as a consequence, improved detail rendition. The pixel size of about 140 µm and the high value of the modulation transfer function (MTF) ensure an image sharpness which meets all clinical requirements, including analysis of fine bony structures (Figs 5, 6).

Integration in the bucky system
The flat construction of the detector allows problem-free integration in bucky systems. As in the Thoravision system, the image data are downloaded on-line from the acquisition system. In this way, the ergonomic advantages of cassette-free operation, with immediate quality control in the examination room, are also made available for standard X-ray rooms.

Flat electronic detector technology

The flat electronic detector provides direct digital registration of X-ray images, without the intermediate stage of optical or mechanical scanning. This has been made possible by the progress in the manufacture of large-area semiconductors which have been developed in recent years, particularly for use in flat computer display screens.

The heart of the new detector is a semiconductor layer of amorphous silicon (a-Si) containing an array of sensors, each with its own switching element. Each of these sensors corresponds to a pixel in the X-ray image.

Amorphous, i.e. non-crystalline, silicon is used in place of the classic microchip with monocrystalline silicon, as this is necessary in order to achieve the large detector area required. Small, monocrystalline CCD sensors in combination with an optical imaging system have inherent disadvantages that lead to a poorer signal-to-noise ratio.

The a-Si layer is brought onto a glass carrier as a thin layer in a vapour deposition process, and structured into an array of sensors (photodiodes) using conventional photolithographic methods. A switching element (a diode or a transistor) is allocated to each individual sensor, so that the sensor can be connected to a readout line in the column direction. The switching elements are controlled via corresponding address lines in the row direction (Fig. 3).

The signals from the individual sensors are read out in sequence. All sensors in the first row are activated simultaneously via an address line. The signals are led in parallel via the readout lines in the column direction to preamplifiers, amplified, and led to an analogue-digital converter. When the first row has been completely digitized, the second row is activated. This process continues until the whole X-ray image has been read out.

As the process is electronic it can, in principle, achieve very high transfer rates. It will therefore be possible, in the future, to use this type of detector for acquiring moving image sequences.

Silicon by itself is not sufficiently sensitive for detecting X-rays in the energy range used in diagnostics. For this reason, an image converter layer is applied over the layer of amorphous silicon. The image converter layer absorbs X-ray photons better than the silicon layer, and converts them into photons of visible light which, in turn, are very easily detected by the silicon. As a rule, caesium iodide (CsI) is used as the image converter layer. This is a fluorescent material, which is also used as the input screen of the X-ray image intensifier. The needle-shaped crystal structure of CsI works as a set of light guides, and avoids the effect of light scatter which can reduce the resolution when other phosphors are used.

The pixel size in the X-ray image is determined by the size of the sensors. In the detector described here, it is 143 µm. This allows a resolution of more than 3 lp/mm to be achieved, which is sufficient for all radiographic applications (with the exception of mammography). With a detector size of 43 x 43 cm a matrix of 3000 x 3000 pixels is created on the flat a-Si detector.

An additional important criterion is the good detective quantum efficiency (DQE) of the new detector. With a value of up to 60%, it is twice as high as that of conventional screen-film systems, giving the possibility of future dose saving without loss of image quality.

The flat sandwich structure of the image detector allows a compact construction (Fig. 4) so that the flat detector can be easily integrated in the bucky table. For the moment, however, the weight and dimensions of the flat detector prevent its being used directly at the patient like a free cassette.

The flat electronic detector:

… uses tried and tested caesium iodide as the conversion layer

… achieves a resolution of > 3 lp/mm with a 3000^2 pixel matrix

… has a high DQE, allowing low-dose operation

… has a compact construction for easy integration

… offers a new perspective for real-time X-ray examinations.

Rapid-sequence imaging
In principle, the electronic readout of the flat detector also allows rapid-sequence imaging [8]. In fact, the prospect that the new flat detectors will be able to replace image intensifier TV systems in real-time X-ray examinations in the future, is a major reason for the great interest in this technology. However, the possibility of rapid-sequence imaging can also have important advantages in radiography, for example in the application of digital tomosynthesis, in the dual energy technique and in stereo exposures.

There is now the question of whether the flat electronic silicon detectors will make cassette-based computed radiography superfluous. This is not expected to happen within the foreseeable future, as the format and weight of the flat detector do not allow it to be used freely around the patient like a cassette, but always make it

Fig. 5 a. Skull phantom with screen-film system.

Fig. 5 b. As 6 a, but with the flat a-Si detector.

Fig. 6 a. Detail of pelvis phantom with screen-film system.

Fig. 6 b. As 7 a, but with the flat a-Si detector.

necessary for it to be integrated in an X-ray stand. This means that bed exposures, as well as projections with special 'free' cassette positions (e.g. cross-table lateral), will continue to be best made with storage phosphor screen cassettes. This technique will also continue to be the method of choice for the less frequently used examination rooms.

The advantages of an X-ray system with an integrated flat detector become particularly evident in bucky rooms with a high workload and a high proportion of standardized examinations. In such cases the automatic operation and the complete digital integration in the workflow of the radiology department make it possible to achieve a significant increase in efficiency. In most cases, this will more than compensate for the initial investment.

Conclusion and outlook

Until a few years ago, the requirement for 'better' images, as well as a general belief in progress, were the driving forces for the introduction of digital radiography. Today, the themes of rationalization of the workflow and reduction of costs are clearly in the foreground. In addition, the requirement for diagnostic quality at least equal to that of conventional techniques and, where possible, a reduction in the patient dose is regarded as self evident.

Due to the additional investment in digital equipment for the radiological department, a saving in costs can only be achieved if digitization results in a reduction in the running costs. The starting points for such a reduction are an increased patient throughput due to an improved and simplified examination procedure, the optimization of image and data communication within the radiology department and between the radiology department and the clinical departments, as well as a reduction or elimination of the costs for disposables, particularly film and processing.

New detectors for radiography must therefore be evaluated, in addition to their diagnostic imaging properties, with respect to their contribution to reaching these goals. In this respect the flat digital a-Si detector offers an important supplement to the already established techniques of storage phosphor radiography (PCR) and digital selenium radiography (Thoravision).

The integrated flat a-Si detector provides a significant increase in efficiency, particularly in busy bucky rooms.

In the digital radiology department of the future, there will be a place for both the flexible cassette systems and for examination systems with integrated detectors. The clinical application will determine which technique can be used most effectively and economically in each individual case.

The challenge to the medical imaging equipment industry is to combine the various components for image acquisition, image communication and image display into integral concepts that will provide the user with the necessary clinical information at the most favourable cost.

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