Going digital can help lower radiation dose

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Every second resident of Europe will, on average, undergo a medical x-ray examination each year. Diagnostic radiology is responsible for the largest proportion of artificial radiation exposure for the European population. The introduction of digital radiography promises to reduce this burden, but to what extent remains unclear.

Digital imaging first entered diagnostic x-ray departments with the development of CT scanners in the early 1970s. Although digital techniques matured slowly, major advances have been made over the last decade. It will be interesting to assess how patient doses have also changed during this period.

Digital technologies are often divided into two groups: indirect and direct readout systems. The first group covers digital fluoroscopy systems with real-time digitization via a television camera output and photostimulable plates that release stored information on laser stimulation. The second group includes systems with an amorphous silicon-based flat-panel readout, where light from phosphors is detected in a photodiode array. It also covers systems with amorphous selenium-based flat-panel detectors that sense charge in a number of ways. CT scanners and charge-coupled devices that allow stored charge to be read out at the end of an exposure fall into this direct category as well.

Digital radiography offers a number of capabilities compared with conventional radiography, such as postprocessing, electronic archiving, concurrent access to images, and improved data distribution. Digital radiographic techniques also have a wider dynamic range, allowing systems to form images from a large range of input receptor doses (approximately 0.05 to 300 micrograys per image). This enables operators to vary exposure levels, within certain parameters, without influencing image contrast or visualization of gray values. Patient radiation dose can thus be lowered, assuming the reduction in signal-to-noise ratio is acceptable and the resulting image quality is adequate to answer the clinical question.

The potential for using a higher dose than necessary becomes clear in an examination of the radiation operating range of different digital modalities. Overexposure in screen-film imaging is recognized easily on a dark film, but this is not the case with digital radiography. Below a dose of about 10 micrograys per image, a change in dose produces a change in contrast resolution. Above 10 micrograys, however, dose changes produce little or no observable effect on the contrast threshold. Practitioners should ensure that digital imaging equipment does not operate in this range. The next step toward system optimization involves assessing what level of quantum noise can be sustained without compromising diagnostic accuracy. Electronic readout noise may limit contrast resolution at very low doses. Theory predicts that threshold contrast at low to middle values of dose per image will follow N-1/2 (where N is the number of x-ray photons/mm2).(1) Efficient use of digital radiography equipment can be guaranteed only by carefully following rigorous and formalized standards of image quality and dose per image.

SYSTEM COMPARISONS

Reports suggest that digital fluoroscopy systems can reduce patient radiation dose by up to 50%. The exact reduction depends on whether image quality is being adjusted to suit diagnostic need and varies by the site under examination. One such analysis of 10,000 barium studies, for example, revealed a 50% dose reduction for patients examined with digital rather than conventional fluoroscopy units.(2) Another group reported that it lowered dose by a factor of 10 when using digital fluoroscopy for pelvimetry, as opposed to screen-film radiography or CT techniques.(3) This result was based on adjustment of radiographic exposure to provide adequate information for the measurement required—and no more.

These examples show how examinations tailored to provide the required diagnostic information, rather than the best image, can reduce radiation exposure. This customization may not be possible.
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with a conventional imaging system. Digital systems are more flexible and can match imaging requirements more readily than screen-film combinations. It is important, however, that users be made aware of any increases in x-ray output made by automated settings.

In general, centers replacing film with photostimulable phosphor plate systems have reported dose reductions of 50% to 95%. One study focusing on skeletal radiography alone demonstrated a 20% to 50% drop in patient dose, with the largest reductions observed during peripheral skeletal examinations. The researchers also noted that the perceived improvement in contrast enhancement from the digital images was useful only in the evaluation of soft-tissue structures. This observation is not unusual in any system in which quantum mottle plays a dominant role. As doses are reduced, high-contrast detail remains while noise-limited information becomes lost in the quantum mottle and might be recovered by an appropriate processing routine. The noise due to quantum mottle is the fluctuation in the number of x-ray photons absorbed per unit area of the receptor. It can be reduced by increasing the number of photons used to form the image.

CCD-based systems offer an attractive alternative to film-based imaging of small areas. CCDs contain integrating detectors but produce little noise, due to the design of their onboard readout. Each pixel can be made to act as a capacitor, storing charge where an electric charge proportional to the beam intensity can be collected. This readout noise is reduced further if the devices are cooled appropriately. CCD-based systems have been used most successfully in dental work and during breast biopsies. Overall performance improvements over film-based imaging come in part from improved quantum efficiency and wider dynamic range. These two factors permit imaging at reduced doses. Practitioners report small dose reductions in general and improved imaging performance at similar dose values.

Detectors incorporating amorphous silicon or selenium are all used in an integrating mode. One early study reported a fivefold dose reduction using an amorphous selenium-based detector. Another study has shown how a large-area flat-panel detector, based on amorphous silicon and thallium-doped cesium iodide, can provide a significant reduction to patients' radiation burden during skeletal and chest radiography. The group reported dose reductions of up to 50% without loss of image quality.

Full-field digital mammography systems use solid-state detectors for image acquisition. Such systems could potentially increase cancer detection rates through their greater photon detection efficiency, wide dynamic range, and improved SNR. Each stage in the imaging process (data acquisition, storage, and display) can be optimized independently. Manipulation of the digital image may also enhance visualization of clinically significant details. Studies on anthropomorphic phantoms have indicated that full-field digital mammography may reduce patient dose by 20% to 35%. More information is needed from clinical trials to assess whether such systems yield significant dose reductions in practice.

The U.K. National Radiation Protection Board (NRPB) reviewed the national patient dose database from 1996 through 2000, comparing the mean total dose-area product (DAP) from conventional and digital spot imaging for 16 different examinations. DAP is the measure of the total energy fluence incident on the patient, and it may be related to the total energy absorbed by the patient. The NRPB found that examinations performed with digital spot imaging had a 20% to 50% lower mean DAP than conventional techniques for eight out of 16 examinations. Little significant difference (8)

RADIATION DOSE IN CT

CT has revolutionized x-ray imaging by providing high-quality cross-sectional images of the body. Introduction of this digital radiographic technique has not reduced patient dose, however. CT examinations account for nearly 50% of the resultant collective dose from diagnostic radiology in some European countries, prompting special measures to ensure optimized CT performance and maintain effective patient protection. European Union legislation now demands that member states pay special attention to radiation protection in CT.

Conditions for radiation exposure during CT examinations are quite different from those in conventional x-ray procedures. Detailed assessment of patient dose from CT requires specific measurement techniques and specially defined dose descriptors. Such assessments can be made using the CT dose index (CTDI). Measurements of CTDI from standard head or body CT dosimetry phantoms provide an indication of weighted CTDI (CTDIw). The volume CTDI (CTDVol = CTDIw/CT pitch factor) describes the average dose over the total volume scanned. This value can then be multiplied by the total exposed length to get the dose-length product (DLP). Evaluation of the DLP indicates the volume of irradiation and overall exposure to a patient during CT examination. EU legislation requires that all new scanners give operators an indication of patient dose. The
International Electrotechnical Commission additionally stipulates that CTDIvol values for each operation selected be displayed on the scanner's console.(12) Most modern multislice CT scanners also show actual DLP values on the user interface. Availability of more applications on CT-cardiac imaging, perfusion angiography, dynamic scanning, and screening for lung or colon cancer in high-risk groups—could potentially increase the collective radiation dose from CT still further. Attention to reducing individual patients' radiation burden can take advantage of options in CT. "Two for one" scanning, in which thick and thin slices are reconstructed from the same data set, avoids repeat patient exposure. Automatic tube current control systems vary tube current along the patient's length without loss in image quality. One such approach relies on local absorption measurements made in the central channels of two localizer radiographs (lateral and anteroposterior). This information is then used to modulate tube current sinusoidally. Another approach uses attenuation-based online modulation of tube current. Both methods can reduce patient dose by 15% to 50%, with no deterioration in image quality. The two strategies will likely be combined in the future.(13)

REALIZING POTENTIAL
Optimizing ionizing radiation use in diagnostic radiology involves the interplay of three key factors: diagnostic quality of images produced, patient radiation dose, and choice of examination technique. The European Commission has produced guidelines covering quality criteria for diagnostic x-ray examinations.(14) An expected extension to these guidelines will cover digital radiography. The commission has also produced a set of quality criteria covering single-slice CT.(11) This publication will similarly be updated to include scanners with up to 16 active acquisition channels.(15)

Many investigators have shown digital radiology to have the potential for dose reduction in diagnostic radiology (see table). Establishment of diagnostic reference doses for standard-sized patients, as stated by the International Commission on Radiological Protection, forms an essential part of quality criteria, and these reference doses should be introduced for all digital radiographic examinations. Quality criteria should be developed to ensure that digital images are not acquired at higher doses than is necessary, and all digital imaging systems should display dose values on the operator's console. This will give trained practitioners valuable information on dose values prior to patient exposure.

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