The Digital Debate

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The long-awaited transition from film-based radiography to electronic review of medical images has begun. There are a number of factors that have influenced this transition. First, picture archiving and communications systems (PACS) have become more capable over the years until the point that the functionality and speed of operation are sufficient to meet most radiologists' needs, all at a price that is affordable. Second, image distribution methods have expanded in scope to include Internet and CD-based viewing methods, reducing referring physicians' reliance on film. Finally, the advent of new, competitive, high-quality projection x-ray image acquisition devices will soon allow for cost-effective replacement of film. This last factor is the topic of this article.

Competing Technologies

Not so many years ago, there was exactly one choice for going filmless-computed radiography or CR. Fortunately, this situation has changed. Now there are a plethora of options, as outlined in Figure 1.

Figure 1. The hierarchy of x-ray detectors

CR remains a bulwark for filmless radiography. CR systems use photostimulable phosphor plates that are read after x-ray exposure by a specialized plate reader. The plates can be used in a cassette that is identical to a film cassette in shape and therefore can be used in existing radiography machines. Alternatively, the plates can be used with a self-contained reader (for example, for chest radiography). The CR plate is simply used in replacement of the film-screen combination. Once the plate has been exposed, it is then transported to the reader either by hand or by a mechanical transport mechanism. The photostimulable phosphor is capable of storing a latent image when exposed to x-rays. The latent image can be read by shining a red light on the plate. This stimulates an emitted blue light, which is detected, amplified, and digitally recorded. An image is produced by scanning a red laser across the plate in a line, and recording the image point-by-point. The plate is then advanced into the reader one line, and the process is repeated until, line-by-line, the complete image is formed (see Figure 2).

CR has several advantages over other methods. First, CR cassettes fit existing x-ray machines. Second, CR supports all cassette sizes. Third, a single CR reader is capable of supporting the workload from several x-ray rooms. Thus, many centers prefer CR because it is less expensive to install. However, the reduced capital costs will be offset in part or in whole by increased operating expenses. With CR, it is still necessary to have the technologist change the cassette between each image, and it is still necessary to carry the cassette to the CR reader. This takes time. In a recent study1, the average time for a two-view chest radiograph was almost 10 minutes (see Figure 3). Moreover, CR cassettes have a limited life expectancy (typically on the order of 10,000 exposures). Thus, a busy imaging center might need to replace all of the cassettes and plates every 12 to 30 months. The plates themselves are relatively expensive.

The biggest advantage of CR is the portability and the physical robustness of the cassettes, thereby simplifying portable radiography, decubitus images, and other more creative projections. The biggest problem is that until recently cassette-less image systems have been too large to allow flexible positioning. This latter problem has now been addressed by a new self-scanning CR system, based on a columnar photostimulable phosphor.2 This new detector is likely to have a form factor similar to the direct digital radiography detectors discussed next.

Up and Coming

Direct digital radiography (DR) detectors are considered by many to be the up-and-coming technology. These detectors are sealed units that are permanently mounted to a radiography system. These DR detectors are electronic devices that directly capture x-rays, and produce a digital image. In general, such devices require that a new radiography system be installed, although upgrade kits are available. If upgraded, many existing radiography rooms would require two of these rather expensive devices. This increases the initial capital cost of converting an existing x-ray facility to being digital. However, the operating costs should be much lower, as the technologist does not have to handle cassettes, the image can be evaluated for image quality in the x-ray room, repeats can be performed immediately, and the detectors have a relatively long life expectancy compared to CR plates. In the study mentioned above1, a two-view chest radiograph took on average only 21?2 minutes with DR.

Figure 2. In CR, a laser scans the image plate from side-to-side, while a motor moves the plate under the laser. The red laser light stimulates blue light to be emitted where x-rays interacted with the phospher during the exposure. This process is called photo-stimulated luminescence. After readout, it is necessary to condtion the plate prior to reuse (not shown).

There are at least three competing technologies for DR detectors. Each of these technologies is constrained by the fact that consumer electronics manufacturers are working to make imaging devices smaller and more compact (generally under 1/2 in), while DR manufacturers must work against this trend by making devices that are the size of the patient. Many of the newer DR systems for chest radiography are 17×17 in. The result is an engineering problem that matches physics against economics.

The first class of detectors that were available used a conventional phosphor-screen imaged by a set of cameras and lenses or fiber-optics. Such systems are relatively easy to manufacture with existing imaging technologies; hence, their short development time. Unfortunately, unless very carefully designed, such systems may exhibit a secondary quantum sink. This refers to a situation whereby little of the light produced by x-rays in the phosphor is actually recorded by the CCD cameras or other imaging device. The result is a device whose image quality depends more on the electronic noise of the camera than the amount of radiation used to produce the image (ie, higher patient dose may be required to achieve acceptable image quality). This problem is complicated because even though a device may be x-ray quantum-noise limited at low spatial frequencies (eg, large objects), most such devices exhibit a secondary-quantum sink for high spatial-frequency objects (eg fine structures in bones).3 The upshot is that finer structures may be hard to visualize due to either blurring or excessive noise. This should not necessarily discourage people from using such systems, as the electronic format provides many benefits, as with all such devices. However, careful scrutiny of images by potential buyers is encouraged. Many in the industry consider such devices a stepping-stone to other DR technologies. Also, given the need to incorporate optics, such devices are still fairly bulky.

Figure 3. Summary of a time and motion study comparing CR and DR. The times stated are from the moment data entry begins on a system (with the patient in the room), until the final image is ready for review. The study considered 2-view chest radiography (CXR), and 2-4 view general radiography. The time to interview and escort the patient to and from the room is not included. These data are derived from the work of DeMaster [1].

The next class of detector includes active-matrix thin-film transistor (TFT) arrays. Active-matrix arrays come in two formats, which are similar in operation, but create images through different x-ray conversion mechanisms (see sidebar, page 18). These arrays are derived for the active-matrix LCD screen technology used in laptops and other flat-panel displays. They consist of a two-dimensional array of pixels. Each pixel contains a charge storage element and a switch. The switch is used to connect the stored charge via a readout line to an output amplifier and other readout chips (see Figure 4). A thorough review of these devices is given by Rowlands and Yorkston4

These devices have many advantages. In general, the image quality is excellent, although each manufacturer's detector should be evaluated for it own merits. This high quality comes from the fact that virtually all of the light or charge generated by the x-rays is recorded and used to make the image. This avoids the secondary quantum-sink described above. However, a new problem occurs in some devices that have small pixels, such as those proposed for use in mammography. Without special design considerations, light sensitive TFT arrays only collect light that falls on the storage element within each pixel. The fraction of the detector that is sensitive to light is called the fill factor. If the fill factor is small, light from some x-rays may never be recorded, again resulting in higher doses. A fill factor of at least 70% is necessary.

Flat-panel TFT arrays have other advantages, including small size, relatively little weight, and fast readout times. As a result, such devices can be used in a great variety of applications, including dual-energy radiography and tomosynthesis (a digital

variant of conventional tomography). Unfortunately, the technology being used is relatively expensive, and also relatively fragile. You do not want to drop one of these! As a result, either they are typically used in a retrofit form factor for existing tables and wall buckys, or in newly designed form factors such as a table-mounted C-arm or a C-arm attached to an overhead tube crane. If such systems are installed in an existing facility, then the existing room may need to be completely replaced. As a result, installing a single DR system may cost as much as installing a large CR unit that might otherwise handle up to three rooms. Proponents of DR argue that its increased efficiency (see Figure 3) partially or wholly offsets this difference in cost.

The final class of detectors consists of scanned-photoconductor devices. One of the first a-Se (amorphous selenium) devices was based upon a scanned optical-discharge method.5 Later, a scanned-electrometer detector was developed for chest radiography. Most recently, a startup Israeli/US firm presented a hybrid scanning matrix detector at the RSNA meeting last year. This flat-panel detector eliminates the need for costly active-matrix arrays, and offers high yields and low defect rates.

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In analyzing the cost of operating film, CR, and DR imaging systems, one should consider initial capital and setup costs, and operating costs. The initial expense will include the equipment costs, site preparation, and installation costs, as well as other associated costs. Cassette-based CR systems have the added expense of a cassette ID terminal in each x-ray room, as well as the cost of the plates and cassettes.

Figure 4. schematic of a direct detection DR array. the a-Se photoconductor is sandwiched between an upper electrode and the readout array. a high voltage is applied to collect charge liberated by x-rays in the a-Se. The scanning control is used to time the readout of the image data through the charge amplifier and multiplexer.

The site preparation should include the cost of existing room demolition; room construction; electrical, network, and telephone installation; and any other associated expenses such as RIS terminals and, in CR, the cost of installing the ID terminals. In addition, the cost of acceptance testing by a medical physicist should be included, as should the cost of acceptance testing the CR cassettes by a technologist.

There are many other costs associated with starting a CR or DR operation. Training personnel, establishing operating procedures, and revising the policy and procedures manual must all be accounted for. In many instances, a new quality control (QC) program will be necessary, and new phantoms may be required. In both CR and DR, if manual techniques are used, then a dosimetry monitoring program will need to be established, as technologists will quickly realize that high mAs images look better than low mAs images.

The operating cost for CR and DR systems should be calculated based on the number of technologists and number of rooms needed. These numbers can be determined from the number of studies that are performed at an institution, making allowances for the utilization of specific, dedicated imaging systems, such as tomographic or chest systems, as well as the time at which studies are performed. For example, many institutions are overbooked during the day, yet a night technologist may be necessary even if only a few studies are performed.

It is typically professed that DR systems will allow greater throughput than CR systems. The requirement of handling cassettes in CR will necessarily introduce delays and inefficiencies in imaging each patient. By comparison, the instantaneous display of an image on a DR console allows the technologist to perform immediate image quality control, and hence retakes take less time. Thus, the patient will typically visit the examination room only once, and the room is occupied for as little time as possible per patient. Many people have used this as the sole justification for switching to DR.

It also is necessary to consider the cost of ancillary personnel, such as fileroom, billing, scheduling, RT assistants, PACS and network specialists, and physicians. Some positions, such as the fileroom, may be eliminated if a department is made filmless. Others may find that the work they perform changes, such as RT assistants who no longer process films, but will assist in other ways. Also, many new jobs will be created, such as IT and PACS support positions. All of these costs must be accounted for. Moreover, if patient volume increases due to reductions in procedure time and increased throughput, then it may be necessary to hire more schedulers or billing personnel.

The Consumable Costs

Obviously, the cost of any consumable supplies must be accounted for. The cost of consumables in film radiography includes the film, the chemistry (fixer and developer), the film jackets and master jackets, and the number and date labels. These costs are significantly reduced in CR and DR. Film will be needed only when a patient or surgeon needs images that leave an institution. Even then, there are alternatives such as Web-based image viewing, CDs, and paper that may be acceptable.

Some costs will still be incurred, regardless of the imaging modality, such as gowns, cleaning supplies, and contrast agents. These costs scale with the number of studies performed. The cost of the electronic storage media must also be included in the cost of operating a CR or DR room. On all of these systems, a service contract or service expenses also must be considered. As a rough guideline, a service contract will cost 10% to 15% of the purchase price per annum. Associated with the actual cost of the service is the indirect cost of? studies not performed as a result of downtime.

It is also necessary to account for the cost of performing QC and medical physics surveys. Again, there is the cost of the labor, and the cost of lost revenues. As both CR and DR require more QC than film, a greater allowance will be necessary, and in some instances more staff will be required, particularly in large PACS environments.

Both CR and DR will require network connections and support, which introduces both capital and operating costs. In many large institutions there are no capital costs for the radiology department, but rather a monthly surcharge is levied on a per port basis. In CR systems, the cost of replacement cassettes must be included.

Finally, the cost of the physical space of the systems must be considered. The elimination of film may allow some darkrooms to be closed or used for other purposes. The exclusive use of DR would allow the elimination of common areas currently used for daylight processors or CR readers. The use of DR may also allow sufficient reduction in examination time to reduce the number of x-ray rooms needed. All of these considerations must be factored into the cost model.

Financing Options

Three financing options exist at this time: purchase, capital leases, and operating leases. The latter goes under many different names, including ASP or application service provider. The acronym might better be listed as xSP, where x depends on the particular vendor.

As the ASP model is fairly new, it deserves some discussion. Under a typical ASP contract, the equipment is provided to a facility at little or no initial cost. The equipment and, often, most or all consumables are paid for on a per usage basis. For example, a dedicated chest DR system may be operated with a per examination fee. An appropriate definition of an examination is included in the legal documents of the lease. At the end of each month or each quarter, a bill is issued based on the number of examinations performed. There may be a lower or upper limit to the monthly fee that can be paid, or the cost per examination may be graded. Depending on these restrictions, it may be possible to move such equipment costs from one's capital budget to one's operating budget. This is a significant difference in many larger institutions that have strict capital controls. The advantage of this approach is that normally all service and upgrades are the responsibility of the vendor and are included in the cost of the lease. Such an arrangement can potentially avoid the problem of rapid technological obsolescence. Such arrangements, however, are typically more expensive in the long term.

In spite of many well-reasoned economic arguments, it may still be preferable to consider one technology over another. For example, if a site has two fully utilized radiography rooms, a waiting list that is growing longer and longer, and does not have room for expansion, then replacing film or CR with DR may be necessary to allow greater throughput. The cost of the conversion must simply be weighed against the cost of not converting, including future lost income. As another example, the lack of trained technologists may motivate a site to convert from film or CR to DR, rather than add another room. This is the situation at a number of areas in the country where trained technologists are in short supply. Such factors are difficult to assign a specific cost to, but may make all of the difference between one technology and another.

As suggested by the introduction, the transition to filmless radiography has begun. All of the elements necessary to build a functional PACS and CR/DR based radiography department exist. While it may not yet be financially feasible or even justifiable for some radiology providers to switch from film to digital, further reductions in price and improvements in image quality and operational efficiency will enfranchise more and more radiology centers each year. Digital radiography is here to stay.

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