The topic of this presentation is digital radiology or digital radiography. Several presentations this week are covering various aspects of this topic.

We are living in a World that exposes us all to a tremendous technology push and depending upon your viewpoint, this can feel like you are either being pushed or pulled by technology at various times. Medical imaging development has markedly increased the tempo with which it is progressing into the current information age. The obvious goal of this progress is to develop new and improved digital techniques for imaging.

Medical images are basically medical information. Automation technology and the transition to digital imaging allows us to acquire and process this information just like other medical information is now being handled. A tremendous amount of resources and research have contributed to the progress in this arena, and it's all being driven by a general movement to electronic imaging. Basic digital technologies have allowed the enabling of this movement to electronic imaging. The radiologists comfort, the clinicians comfort, the patients comfort, etc., has slowly evolved into a positive mode in reference to electronic imaging. This has not occurred immediately. Comfort and confidence have taken time to make progress and in many instances is or will be the part of this conversion which lags behind the technology.

We have increased mobility of patients in our society. Not only in the military where our patients are moving around quite frequently as part of regular military life, but also in the civilian population. This mobility is another factor which pushes us toward electronic imaging with the potentially greater mobility of electronic images. There are also external demands upon the medical community for improved measures of quality control and risk management, and also internal demands with greater requirements for improved quality of the products that we produce.

This year we celebrate the 100th anniversary of the discovery of X-rays, from 1895 to 1995. For tens of decades, we basically had only plain film-based radiology and fluoroscopy. The expansion of imaging modalities in the 1950's and 1960's saw the introduction of video fluoroscopy, nuclear radiology and ultrasound.

In the early 1970's a purely digital imaging technique was introduced into the imaging diagnostician's armamentarium. This was computed tomography (CT). Following CT, all new imaging modalities which have been introduced and are widely adapted are really purely digital imaging modalities. Single photon emission computed tomography in nuclear medicine, positron emission tomography, digital fluoroscopy, and digital subtraction angiography, and computed radiography. Digital fluoroscopy and computed radiography allow the replacement of the some of the analog components in the imaging chain that we have had since the late 1800's and early 1900's. Teleradiology also started as a video broadcast type of transmission of images and then with the development and presence of microcomputer systems, became a digital modality. Magnetic resonance imaging, angiography and spectroscopy, and now magnetic source imaging have all begun as purely digital types of techniques.
What digital radiography allows us to move away from is the film. Plain film based radiographic imaging comprises approximately two-thirds to three-quarters of typical radiology department examinations. Film based images have many critical limitations. One of the most important is that they can be lost. Subsequent difficulties in patient care and management arise when the patient's radiographic record or history is lost. Lost images/films basically represent lost time for many individuals in the health care chain and increased or needless radiation burden for the patient and technologists. When film/images are lost, time is lost to the patient, to the clinician, to the radiologist, to the technologist and to the personnel employed to manage and keep track of the images. There is additional radiation exposure involved with the patient when examinations have to be repeated. The patient and the healthcare providers have lost a very important snapshot in time: the radiographic history of the patient.

Two different modalities will be covered in more detail. These have truly enabled us to move into full departmental digital radiology format. Over 70% of a typical radiology department's workload is comprised of the classic "plain film" and fluoroscopy. Digital fluoroscopy allows direct digital capture of fluoroscopic examinations. A typical installation incorporates a digital image intensifier with presentation of the images on a computer work station or monitor located directly in the fluoroscopy room. These are typically 512x512 or 1024x1024 matrix images. This equipment the capability of acquisition of dynamic acquisitions with six or more frames per second, and inherent storage of more than a hundred images in the system. Of course, the images can be moved to larger storage systems after they are acquired, such as a large magnetic cache or optical storage.

Compared to film, digital fluoroscopy has a lower spatial resolution, but much greater dynamic range or contrast resolution. There is immediate display of images, and any images that were not adequately obtained in the fluoroscopy room during the initial performance of the examination can be immediately repeated. This obviates having to wait for the film to go through the processor and then bringing the patient back in, and going through a lot of delays. This results in faster service for the patient and more efficient operations for the radiology department. The digital images are available for post-processing, storage communications, and display just like any digital image is after its acquisition.

Computed radiography (CR) is a technology developed in the early 1980's which will accommodate direct digital acquisition of about two-thirds of the film-based radiography that is practiced in most radiology departments. It has a comparable spatial resolution to high-speed film screen systems and a much improved contrast resolution compared to film. This imaging process is based upon the capture of X-rays on an imaging plate (IP) instead of on a sheet of film inside of a cassette. The cassettes fit in standard radiographic equipment so that the installed base of radiology equipment does not have to be replaced with the introduction of computed radiography. After the plate has been exposed to radiation during the exposure of the patient, it is placed into a CR reader machine and the IP is removed from the cassette. The plate is then scanned by a laser beam imparting additional energy into the molecular structure of the plate. This results in the subsequent release of energy in the form of light which is capture, amplified and digitized. The released energy is proportional to the number of original X-rays captured by the IP during the initial exposure. This digitization results in creation of the radiographic image in the CR reader's memory. The digital image is now available for processing, the initial step of which is a quality control step.

Technologists used to put film up on the view box and review the films there to be sure that the examination was complete and adequate. Now they look at the images on a workstation monitor. They look at the soft copy images, make their decisions, determine what needs to repeated, if anything, and then send the examination on to the radiologist. All of this is capable of being accomplished electronically in a networked picture archiving and communications system (PACS).

ROC studies have found that the computed radiography images are comparable to film screen images. These investigations
have paved the way for CR to enter into the mainstream of radiologic diagnosis. Recent advances in computed radiography have improved the speed of the readers and resulted in the capability of processing more plates per hour. Also, improvement has been achieved in imaging plate development itself. This has resulted in higher resolution for the larger sized imaging plates, making it possible to achieve up to five line pairs per millimeter of spatial resolution for the larger plates. So, the main characteristics of computed radiography include a slightly smaller spatial resolution than film screen and a wider or greater dynamic range. This improvement in contrast detectability has been shown to greatly over shadow the slightly decreased spatial resolution. Just like with digital fluorography, the digital computed radiographic image is also available for all of the standard image processing, transmission and storage capabilities associated with any digital image.

The introduction and transition to fully digital image acquisition devices has made possible the introduction of picture archiving and communication systems or PACS systems. All of the images acquired from the different modalities within radiology can be stored digitally, transmitted over communication networks, displayed on monitors on workstations, stored on permanent storage devices such as optical disks or tape, and can also be made available for remote transmission (teleradiology).

In the modern film-based image library, marked amounts of space and personnel are required to maintain a reliable and efficient film management system. At BAMC we had over 4,000 linear feet of film prior to embarking on the digital transformation of the Radiology Department. Image management in the film-based department is particularly difficult when space constraints and widespread imaging modalities have resulted in a distributed or fragmented film library system. Digital archiving allows a marked compression of storage space on optical disks. Optical disk jukeboxes utilizing image compression techniques can store greater than one million chest radiograph equivalents on-line. Archiving requirements are tremendous in a digital radiology department. A radiology department of moderately large size (180,000 examinations per year) will produce approximately four terabytes of information per year in medical imaging. This equates to about 11 gigabytes per day. If one compresses this down to a "busy six hour day", approximately 30 megabytes per minute of new medical information being created. This volume of information must be handled in a digital department including storage, transmission and display. Additional information management capacity is required for movement of historical images for comparison with the new imagery.

The development of high resolution (2K) monitors for workstations has allowed the introduction of soft copy reading. Digital dictation can be utilized to record the human voice digitally. The radiologist's voice can be listened to by the clinician separately or while viewing the images of his patient.

Having digital information and these other tools within a facility opens the possibility for the advent of teleradiology and the sharing or transmission of medical imagery over distance. The basic processes involved with teleradiology are image acquisition, association of the images electronically with patient demographics, storage and display, and communications between different facilities. Other presentations at this forum will cover teleradiology and the telecommunications technology required for this aspect of digital radiology.

A prime concept which must be determined early in the implementation of teleradiology is whether your purpose is primary diagnosis or consultation because the communications bandwidth as well as the image display requirements are markedly different for these two ventures. Basic teleradiology can involve simply the digitization of films from a remote site and transmission of the electronic images via either telephonic or satellite communications back to a medical facility for immediate consultation or diagnosis.

Inherently digital devices, such as computed tomography can also obviously be transmitted in the same manner without the requirement for production of an initial film. The U.S. Army deployed two field CT scanners to Saudi Arabia during the Gulf War. Images were communicated back to the
United States for consultation on many CT cases. Various image transmittal patterns are currently being utilized by the U.S. military in Korea. A teleradiology system with six nodes is present and in daily use. Various configurations within the United States between military facilities have been designed for transmission of images and are under implementation.

We will eventually move beyond the advent and novelty of teleradiology into telemedicine where we will see full clinician acceptance and utilization of electronic images for remote clinical diagnosis. Our new facilities need to be equipped appropriately, so that we not only can send radiologic images, but we are able to send live audiovisual images along with them in the company of additional patient demographic and graphical information.

Problems do exist as we progress further into the digital world and these must be addressed as we move forward. Speed in image display and manipulation must continue to increase and cost must come down. The technology marketplace has shown us that this will occur. One crucial problem requiring resolution is the interfaceability or compatibility between different vendors of equipment. We must be able to take one component out and put another one into a digital electronic system which is compatible with the remaining equipment. End users of technology must require compliance to interface standards in the equipment that they will purchase. Another important problematic issue is the user interface. Our technologists and clerks and ourselves can become overwhelmed with new technologies. We must diligently guard against problems in the human interface and require optimization of digital technologies, physical layouts in work areas and sufficient/adequate training to assure successful introduction of digital means into the day to day practice of radiology.