Teleradiology: A Historical Perspective

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Abstract

The functionalities available in a modern radiology department are rooted in the proving grounds of the late 1980's and 1990's. The workflow has gone from live video connections where the sending and receiving parties had to be scheduled to be available simultaneously since the medium was live video transmission. This technology was left for the "store and forward" approach afforded by the digital age. The industry responded with new standards for the interchange of radiologic data. Both the US Military and NASA had the resources to lead the curve on successful implementations. Concurrent to the validation and acceptance of the new technology, change management and legal issues emerged. The industry of teleradiology is growing quickly with new business models. As we look to the future, the technologies of PACS and teleradiology are inextricably mixed.

Introduction

A radiology department or imaging center exists as a complex array of advanced technological equipment designed to produce one thing- that being information. While on the surface it appears that the final product is an image, the true goal is the report from the radiologist. As the growth of technology brought us to the digital age, so too did radiology evolve. The concept of teleradiology became mainstream in the late 1990's, after many contributions from both trailblazers in the medical community and the US military. Early adopters of the technology sought to prove credibility which gave way to an explosion in the marketplace. The expectations for the Picture Arching and Communications System (PACS) and teleradiology systems of a modern radiology department are immediate image availability from both inside and outside the facility. The portability that digitized images afford the system, allow for multiple solutions from the business world for producing that product- the radiologic report.

An Evolution

The simplest definition of telemedicine is: "medicine delivered at a distance". The prefix "tele" is a derivation of the Greek term meaning "remote or at a distance". To stretch the definition, some would argue that telemedicine has been in existence as long as the telephone. Teleradiology is a natural outgrowth of telemedicine, where technology is tailored for the purposes of interpreting radiological data. Table 1 gives a rough timeline of Telemedicine development, after the 1990's the growth accelerated rapidly.

Table 1. Main phases of telemedicine development

Development phase	Approximate timescale
Telegraphy and telephony	1840s- 1920s
Radio	1920s onwards (main technology until 1950s)
Television/space technologies	1950s onwards (main technology **until** 1980s)
Digital technologies	1990s onwards

SOURCE: Norris, A.C. 2002. *Essentials of Telemedicine and Telecare* (West Sussex, England, New York: Wiley and Sons Ltd.) Figure 1.1. p. 6

NASA and Rural Health

Teleradiology is "the ability to obtain images in one location, transmit them over a distance, and view them remotely for diagnostic or consultative purposes"[1] One can almost immediately imagine the benefits for those injured in remote locations who require the expertise of a radiologist for the proper interpretation of their radiological data. It is no surprise then that much of the pioneering work in this field has been done by both the United States military and the National Aeronautic Space Administration (NASA). Teleradiology is a natural outgrowth of NASA's telemedicine initiatives. Initially, astronauts' physiologic markers were monitored to determine the effects of flight, launch and reentry. As early as the 1950's twenty year collaboration between Lockheed, the US Public Health Service and NASA was designed to serve the rural communities of the Papago Indians in Arizona. The project, Space Technology Applied to Rural Papago Advanced Health Care (STARPAHC) served as a means of transmitting both electrocardiographs and xrays to centers staffed by medical specialists.[2]

Early teleradiology projects were specially funded and sought to serve remote populations, where radiologists were not readily available. These projects relied on the installation of new and dedicated systems for data transfer such as facsimile machines or specialized computer technology. As the bandwidth availabilities have increased over time, so has the application of this concept. Teleradiology is no longer seen as just a solution for the remote patient, but as a means of convenience for the radiologist and for several companies, a whole new business strategy.

Teleradiology: 1960's and 1970's Style

The precursors of today's slick teleradiology systems have their roots in the closed-circuit broadcast systems of the 1960's. In 1955, the Nebraska Psychiatric Institute developed a two-way link with Norfolk State Hospital, 112 miles away. The

[1] Thrall, James H, 2007. "Teleradiology Part I. History and Clinical Applications" *Radiology* 43:613– 617

[2] Norris, A.C. 2002. *Essentials of Telemedicine and Telecare* (West Sussex, England, New York: Wiley and Sons Ltd.) p. 6

links were further enhanced in 1964 and 1971. This was one of the first examples of telepsychiatry where specialists and general practitioners could consult for education and treatment. [3] Facilities also installed in-house teleradiology solutions. One at the Walter Reed General Hospital in Washington D.C. connected the emergency room and radiology departments with a closed-circuit television system. These systems were extremely limited both by the low image quality and investment requirements for dedicated installations. Images had to be viewed at the same time at both locations as it was a video signal being transmitted, not a series of still frames available for manipulation at will.[4] Initially, it was expected that commercial television would be adequate for the diagnostic purposes of radiological films. It was found that neither the 525 lines of commercial television nor the 945 lines of the closed-circuit high-resolution were a good replacement for radiological films. Any attempts to zoom in on the images resulted in increase in spatial resolution, but also in the signal-to-noise ratio.[5]

In 1975 a study on the diagnostic quality of films transmitted via 525 line television was conducted between Massachusetts General Hospital (MGH) and the Veterans Administration Hospital (VA) in Bedford, Mass. The hospitals exist 14 miles apart, and the images were transmitted via microwave link from MGH to the VA and back to MGH. There were one hundred images read by five radiologists. The test equipment included a tube television for displaying the images, and a pushbutton/joystick interface which allowed him to control iris opening, focus, x-y pointing of the camera and zoom. Each was read twice, once from traditional film, and once over the television link. The two views were presented at 2 month intervals, to minimize the effects of memory. The results of the study provided some promising evidence for the continued pursuit of viable teleradiology technologies. “With a modest amount of experience in the technique, the radiologist should become comfortable with the necessary manipulations and familiar with the television appearance of the film”[6] This design was still limited to a short-range distance and only practical for diagnosing conditions which required the display of several images. One can hardly imagine hanging and manipulating the several hundred to several thousand images CT and MR studies which now comprise a typical diagnostic set in this manner.

The 1990’s- A proving ground for PACS and Teleradiology

In the 1990’s, teleradiology started to exploit some of the Wide Area Network (WAN) capabilities available. Communications took place over copper wire, coaxial cable, fiber-optic links, digital switched circuits and microwave and satellite links. In addition to these improvements in speed of transport, new means of providing digital images were in wider use. Since most imaging modalities were still analog, film digitizers were added to teleradiology systems. A digitizer scans a piece of film and creates a digital picture of it. The advantage of digitized images is, they are readily available for transfer over any

[3] Norris. p. 6
[4] Thrall. p. 614
[5] Batnitzky, Solomon MD, 1990, “Teleradiology: An Assessment,”Radiology Vol 177, pp11-12
[6] Andrus, Scott W MD, Dreyhuss, Jack R MD, Jaffer, Faroq MD et al. 1975, “Interpretation of Roentgenograms via Interactive Television”, Radiology Vol 116, pp 25-31

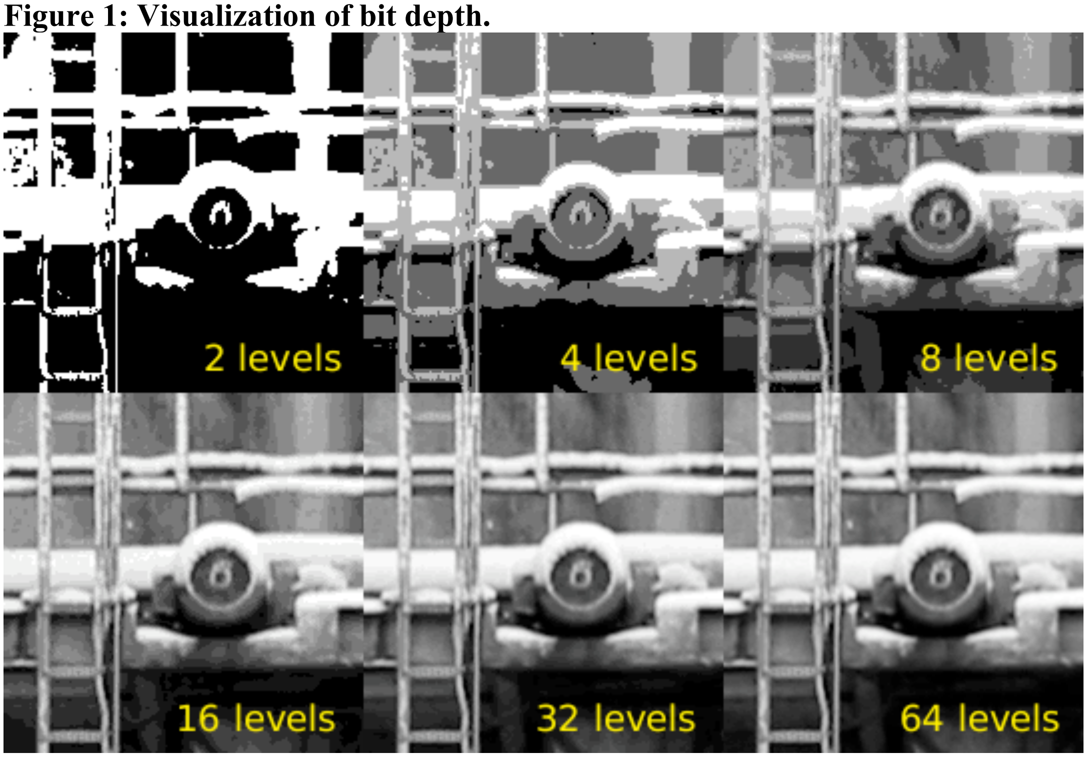
available transport method. This new mode of "store and forward" was highly preferable to the earlier generation's live video feed. The store and forward approach did not require the simultaneous coordination of staff at each location. Early digitizers provided low resolution; 512 pixels by 512 pixels with 8 bits of depth. Figure 1 shows the differences among bit depths. Later improvements in digitizers increased the bit depth to 12 or 16 bits. Table 2 shows the calculated available shades of gray for reference.

Table 2: Bit Depth and Available Grayscale Values

Bit Depth (number of levels)	Available grayscale values
2	2
4	16
8	256
16	65,536
32	4,294,967,296
64	18,446,744,073,709,551,616

Visually, one can appreciate the differences among the low bit depths. As the available grayscales increase, the differences become increasingly subtle.

Figure 1: Visualization of bit depth.



SOURCE: Kolås, Øyvind, 2005 [Internet, WWW, Computer program] ADDRESS: http://pippin.gimp.org/image_processing/chap_dir.html [Accessed 29 October 2007].

The necessity of the digitizers arises from the overwhelming use of conventional screen-film radiographs in a typical imaging department. Nearly three-quarters of the workload can be attributed to these traditional x-rays.[7] At this time, imaging modalities were designed to send to a dedicated printer. The only available infrastructure for moving films is now referred to as "sneakernet"; put your sneakers on and take it there.

The prevalence of teleradiology systems was still quite low. The systems were very expensive and the level of infrastructure had not quite grown enough to support widespread adoption of this evolving technology. At this time there were less than 25 such systems deployed and the cost for each was over twenty million dollars. This variety of system architecture is now considered obsolete.[8]

Bosnia-Herzegovina: A victory for Teleradiology

In late 1995, the US government deployed twenty thousand troops to Bosnia-Herzegovina as part of a North Atlantic Treaty Organization (NATO) peace-keeping force. Complementary to the troops, a full medical support facility was established in Bosnia. For the first time in military history, the entire radiological workload of a Mobile Army Surgical Hospital (MASH) was supported by radiologists hundreds of miles away. The system was designed with the emerging Digital Imaging in Communications in Medicine (DICOM) 3.0 standard in mind. While not all modalities came ready to interface with the DICOM network off the shelf, third party solutions for DICOM conversion were also used. The implementation was designed to be film less. That is to say, the images were acquired, transmitted and read digitally without film being generated. Printing and digitizing equipment was added to make occasional hard copy images for non-US troops. The transmission of images was accomplished over a combination of microwave, satellite and leased high bandwidth lines.[9] The deployable teleradiology system, coined DEPRAD, provided a meaningful example of the viability of the concept of teleradiology. With the combination of the financial resources available at its disposal, and the projected radiologist caseload for ensuring the health of the US troops, DEPRAD proved that even in a war-zone, a successful design and implementation could be accomplished.

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[7] Batnitzky, Solomon MD p. 12
[8] Nagy, Paul G, 2007, " The future of PACS", *Medical Physics*, 34, pp 2679
[9] Levine, Betty A, Cleary, Kevin, and Seong, K Mun, 1998, "Deployable Teleradiology: Bosnia and Beyond", *IEEE Transactions on Informations Technology in Biomedicine*, Vol 2, pp 30-34

The Human Element: The Real Challenge

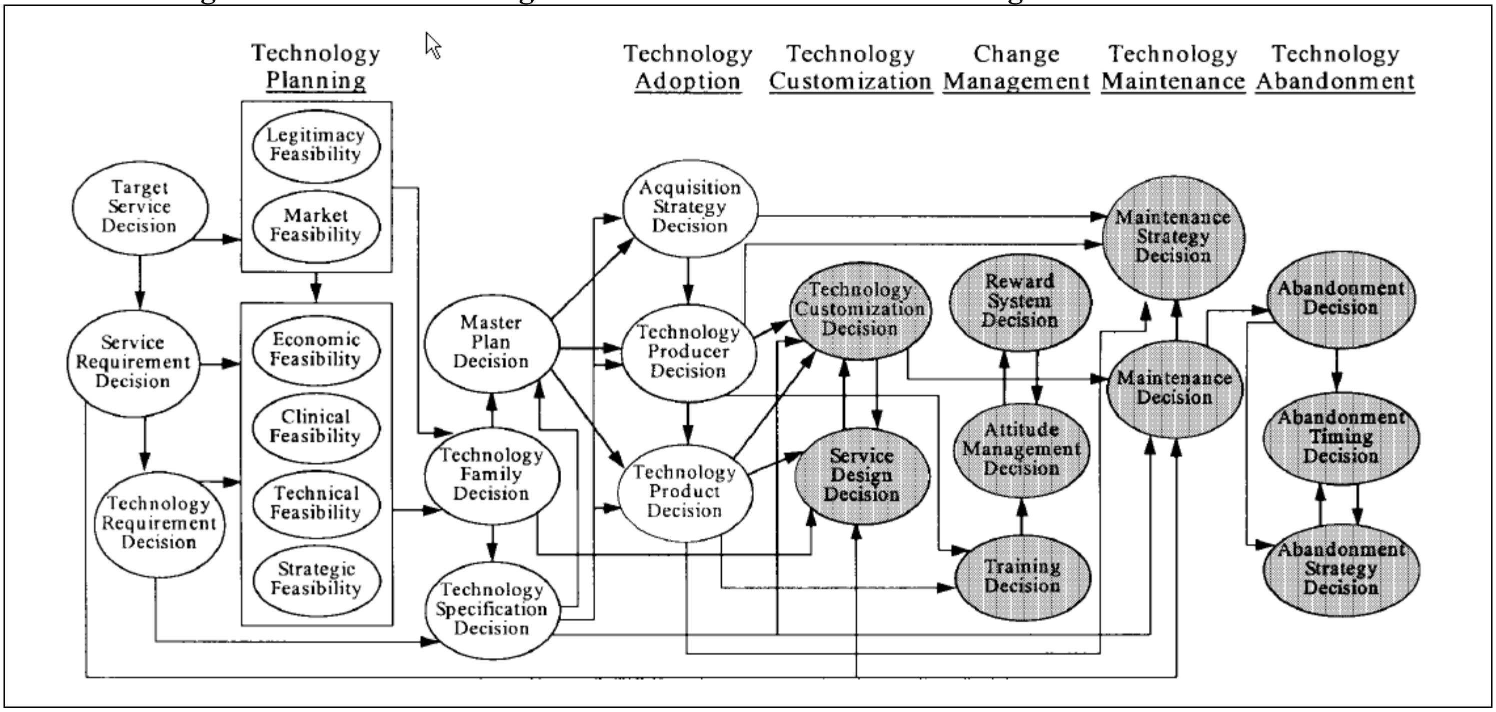
As the feasibility of a teleradiology solution was taking hold in the radiology community, new realizations about the challenges related to the requirements of change management surrounding the installation of such a system were being noted. In the case of the DEPRAD installation, the military hierarchy ensured all parties followed commands as they come down the chain. In the corporate world the observation is: "..health care organizations are unique in several ways. For example, individual autonomy is relatively high among member physicians, who often exhibit varying degrees of professional dominance over management and customers (ie patients)"[10] Indeed, many facilities were feeling the pain of a poorly planned implementation phase. The technology planning is the marrying of the organization's needs with the available technologies. Once the decisions have been made, there are still many important steps. Teleradiology systems need to be customized to an individual organization's workflow, and then most importantly the change management steps need to be handled. In the article by Sheng et al the change management piece is summarized as follows:

> "Change management is crucial because, in most cases, physicians have enough individual autonomy to determine the ultimate fate of an adopted technology. Effective change management can ease the minds of physicians who worry about changes in their stakes within the organization before and after the technology implementation."[11]

Figure 2 is a flowchart visualizing the decision-making framework for telemedicine management decisions. A successful teleradiology implementation will also appreciate the cross-functional cooperation required to accomplish a successful system.

[10] Sheng, Olivia; Hu, Paul and Wie, Chih-Pei, 1999, "Organizational Management of Telemedicine Technology: Conquering Time and Space Boundaries in Health Care Services" *IEEE Transactions on Engineering Management*, Vol 46, p. 265.
[11] Sheng, Olivia et al, p. 271.

Figure 2: Decision-making framework for telemedicine management decisions



SOURCE: Sheng, Olivia; Hu, Paul and Wie, Chih-Pei, 1999, "Organizational Management of Telemedicine Technology: Conquering Time and Space Boundaries in Health Care Services" *IEEE Transactions on Engineering Management*, Vol 46, p. 271

DICOM: The Common Radiology Currency

As computer networking grew in popularity, the need to network imaging equipment was recognized and the DICOM was jointly created by American College of Radiology (ACR) and National Electrical Manufacturers Association (NEMA). The standard is a self-managed set of best-practices and rules for the transmission and exchange of medical imaging data. This open protocol concept allows for all equipment to communicate in a multi-vendor environment. The predecessors to DICOM were all proprietary. Each vendor had a separate set of rules for communicating its images, and often their own cabling requirements. DICOM protocol rules exist in the application layer, so they are independent of transport. That is to say, they will work over gigabit, 100Mbit or wireless. As there is no built-in security in TCP/IP, issues of privacy and security must be addressed at a network level.

What DICOM does ensure, is a unique identity for each study and image. The standard demands a Unique Identifier (UID) to be tagged in the header of each study and image. The specifications of the UID are such that it is unique in the world. This has important implications for portability of an image as facilities share patients' radiologic data.

Even in the 1990's a digital modality did not guarantee network portability. Many vendors could only export images in either a proprietary format or only had an interface for the printer. This was a major hurdle for PACS and left a short-term market for so-called "DICOM boxes". These small, dedicated computers either took over the camera control cables on the digital devices, or were calibrated to take a screen capture of the image being displayed on the modality monitor. They provided both a niche market for several vendors, and a bridge for the older modalities into modern radiology department topologies. An image that can be digitized at the point of the acquisition was a highly preferable workflow decision and created more consistent image quality than the stand-alone film digitizer. A lesson from the DEPRAD installation during the Bosnia-Herzegovina conflict: "A system integration effort of this magnitude could not have been accomplished in the compressed time frame (90 days) had DICOM not been used."[12]

PACS and Teleradiology: Technology Partners

The advances in teleradiology are closely tied to those of modern PACS. Today, a teleradiology solution will likely be a subset of the already existing PACS system. The same images which are viewed inside the hospital building are available offsite both for diagnostic and reference purposes. Current teleradiology methodologies include a "push" where images are sent specifically to a physician's home and/or a night reading service, a "pull"over the internet using SSL encryption technologies or the viewing of images over the facility's VPN. Additions to the DICOM standard allow for lossless compression of most medical images. These are highly preferable for teleradiology since ratios of 10:1 compression can be achieved for several image types without any loss of diagnostic information.

Teleradiology: A petrie dish for legal issues

The early days of teleradiology were not fraught with the legal concerns of today. The growth of both broadband technologies, and advanced imaging storage architectures mean that images can be transmitted regionally, nationally and even internationally for the purposes of emergency reading by a radiologist. With the current availability of broadband communication solutions, the teleradiology network topology only differs in larger physical spans of space between the acquiring institution and the reading radiologist. This is an element which will be transparent to both the patient and the attending clinicians at the point of care. There are, however, specific legal and reimbursement concerns which arise when the transmission and interpretation of images crosses international borders. Medicare will not reimburse for services performed outside the United States. The Centers for Medicare and Medicaid state the following as a guideline for reimbursements:

> "Payment may not be made for a medical service (or a portion of it) that was subcontracted to another provider or supplier located outside the

[12] Levine et al. p.31

> United State. For example, if a radiologist who practices in India analyzes imaging tests that were performed on the beneficiary in the United States, Medicare would not pay the radiologist of the US facility that performed the imaging test for any of the services that were performed by the radiologist in India"[13]

The overnight read is typically treated as a preliminary report. A finalized report will be dictated and signed by a facility's staff radiologist the following day. A chief concern among hospital administrators is the potential for differences between the overnight read by a remote physician and the dictation performed by the facility's staff radiologist the next day. In addition to the potential for providing substandard care, ACR has raised an ethical issue regarding a physician digitally signing and billing for an interpretation made by another physician. ACR has expressed the following:

> "It is unethical and likely fraudulent for a physician who has not personally interpreted images obtained in a radiologic examination to sign a report to take attribution of an interpretation of that examination rendered by another physician in a manner that causes that reader of a report to believe that the signing radiologist was the interpreter."[14]

The Joint Commission on Accreditation of Healthcare Organizations (JCAHO) has raised concerns with the standards of care delivered when radiological diagnoses have been rendered from a remote location. "Leaders must make sure that factors such as different individuals providing care, treatment and services, different payment sources, or different settings of care do not intentionally negatively influence the outcome of care"[15] The technology of teleradiology has been proven, however there is still trepidation in the healthcare community regarding its accuracy and potential effects on delivery of care. The rate of disagreement on diagnosis by teleradiologists should not be significantly statistically higher than in standard practice. These studies are carried out on an ongoing basis.

New business models – NightHawk and Teleradiology Solutions

The combination of radiologist shortage combined with an increased utilization of radiology services, new business models have emerged. Between the years of 1999 and 2004, imaging services took the lead in growth compared to any other physicians' services paid for by Medicare.[16] The name of the company NightHawk has become synonymous with off-hours reading. They are the largest teleradiology company in the United States and employ over one hundred radiologists. To keep current on legal matters, Nighthawk employs more than thirty five people to do its credentialing work.

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[13] Rozovsky, Fay, and Goodwin, Susan, 2007, "Teleradiology: Compliance Concerns and Solutions, Part III" *Journal of Health Care Compliance,* vol 9 pg.16
[14] Rozovsky, Fay p. 17
[15] Rozovsky, Fay p. 18.
[16] Steinbrook, Robert, p.5

Their average radiologist holds state licenses in 38 states.[17] This model has proven to be highly profitable. In the second quarter of 2007, Nighthawk posted a sixty-six percent revenue growth over the same quarter in 2006.[18] In another similar venture, the company Teleradiology Solutions was founded by a husband-and-wife team of Yale trained physicians. The company is based in Bangalore, India with a US office in New Haven, CT. According to an article last year in the New England Journal of Medicine: "The technical and logistic hurdles of remote teleradiology have been overcome, and the practice of having radiologists who were trained and credentialed in the United States read films overseas is now largely accepted."[19] Only time will tell how the global market may or may not absorb the over-abundance of radiological studies to read paired with the relative shortage of radiologists.

On the horizon for Teleradiology

The futures of teleradiology and PACS are knit together, as the advancing technologies blur the lines between onsite and remote access. The future architecture of a PACS/Teleradiogy solution will be distinguished by server-side rendering. The growth of data acquired will divert the processing from the workstation back to the server. The bottleneck will no longer be the speed of the disk storing the images, but the bandwidth available on the network serving those images.[20] This will be a factor both within the facility where traditional reads take place, and remotely in the teleradiology sector. The move is already towards storing images, even long-term, on spinning disk. Previously, Hierarchical Storage Management (HSM) solutions moved images to slower media given a certain timeframe or watermark of free disk-space. While the HSM solution is still viable, the burden of restoring those images in the event of catastrophic failure of the primary system is on the order of months to years.

A major consideration will be scalability. There will only be an increase in the demand for disk space as new modalities are introduced as clients to the PACS services. Already, digital mammography is impacting storage decisions made years earlier. There is also a call for better interoperability among vendors who provide post-processing applications such as volumetric imaging and radiation therapy planning. Currently, these exist as separate systems even to the point that the stored exam needs to be copied to another system to perform the desired task. "It is becoming increasingly untenable for radiologist to sacrifice productivity while tethered to specific locations needed to gain access to sets of specialized tools"[21]

[17] Steinbrook, Robert, 2007, "The Age of Teleradiology" *New England Journal of Medicine*, Vol 357 pg. 5
[18] **Bland, Charles R. Science Letter Oct 2, 2007 pg 4091**
[19] Wachter, Robert, 2006, "The Dis-location of U.S. Medicine- The Implications of Medical Outsourcing," The New England Journal of Medicine, 354, p. 663.
[20] Nagy, Paul G, 2007, " The future of PACS", *Medical Physics*, 34, pp 2679
[21] Nagy, Paul G p. 2680

Conclusion

It's hard to imagine going back in time and being impressed with the primitive television transmission teleradiology systems of just the last generation. The explosion of technology within the last twenty years has left a modern radiology department only a distant cousin to those of the past. Even in my short career in the PACS trenches, I have witnessed significant strides in the quality, quantity and availability of images. Just ten years ago, when I embarked on my PACS career, I was retrofitting legacy imaging equipment with digital conversion boxes so they could readily interface with network printers, third party imaging workstations, PACS and teleradiology solutions. Within this short timeframe, these boxes are virtually extinct as vendors have accepted the DICOM standard of communication as a method for imaging data interchange. The power of the portability of images has been a positive step towards empowering consumers in the management of their own healthcare. The growth market of off-hours reading has certainly been exploited by several companies. These companies have won great profits and their radiologists have reaped the benefits of a work-at-home environment. Teleradiology has become a familiar term in medicine, as the emerging technologies of the twenty-first century close the time and space gap between physician and patient.

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