Teleradiology

Part I. History and Clinical Applications[1]

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Teleradiology—the ability to obtain images in one location, transmit them over a distance, and view them remotely for diagnostic or consultative purposes—has been explored for nearly 50 years and is part of the more encompassing concept of "telemedicine"—the delivery of health care services over a distance. Major advances in telecommunications and computer systems and advances in the ability to capture medical information in digital form have accelerated the ability to apply telemedicine methods in a practical and affordable manner. These enabling factors are especially relevant to radiology, which currently stands out as one of the most technologically and clinically advanced areas for telemedicine applications.

The Rise of Telemedicine and Teleradiology

On March 10, 1876, Alexander Graham Bell (1,2) spilled battery acid on himself and summoned his assistant, Thomas Watson, saying "Mr Watson, come here. I want you!" History records that Mr Watson heard Bell's voice through the wire of the telephone system that they were in the process of inventing, thereby signaling the simultaneous beginnings of telephony and telephone-based telemedicine—a summons for help with a medical emergency. Telephonic voice communication among providers, between providers and patients, and between other stakeholders in health care delivery is a ubiquitous telemedicine application that we all probably take for granted but without which the health care system would grind to a halt.

In the ensuing 130 years from the invention of the telephone, every new method of communication has been explored for use in telemedicine applications. When touring the Queen Mary ocean liner several years ago, I was intrigued to see a display from the 1930s that described the use of the ship's marine radiotelephone to receive and provide onboard medical consultations. The ship carried a physician as part of its crew and had a medical clinic complete with a radiography machine and surgical table. The radiotelephone provided access to outside medical expertise and, likewise, allowed the Queen Mary's medical officer to help those on other vessels.

Extensive exploration (3) of closed-circuit and broadcast television for patient consultations and for transmission of medical images from several specialties—radiology, pathology, and dermatology—was performed in the 1960s and into the 1970s. Among other investigators in this time frame, Dr Kenneth T. Bird of Massachusetts General Hospital (Boston) established an interactive television system (4) using direct microwave transmission from Logan Airport in Boston to the hospital to provide care for travelers.

In a similar vein, the Walter Reed General Hospital (Washington, DC) installed a closed-circuit television connection between the department of radiology and the emergency room some time in the mid-1960s. It was still in place when I began my internship there in 1968, but poor contrast and spatial resolution and the need to send each image sequentially one at a time relegated the system to novelty status, and it was never used seriously for patient care. High costs for dedicated installations, poor image resolution, and cumbersome logistics doomed the use of conventional television as an important medium for telemedicine (3). For the most part, television-based demonstration projects from this time period were terminated after these limitations were recognized.

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In the 1970s and gaining momentum in the 1980s, attention turned to computer-based approaches to telemedicine, with a shift in interest from real-time television applications to "store-and-forward" methods (3) in which data are collected in digital form at an initiating site and are aggregated and stored for subsequent transmission to a receiving site. The store-and-forward approach simplifies operations by eliminating the need for all parties—patients, providers, and other support staff—to be present at both sites simultaneously.

The store-and-forward approach is now the basis of teleradiology and many other telemedicine applications in which telemetry of data rather than direct televised face-to-face or voice contact between patients and providers can be used to deliver the service. Other services provided in this way include teledermatology, telepathology, interpretation of electrocardiograms, and home monitoring of patients (ie, measurement of heart rate, blood pressure, and weight).

The National Aeronautics and Space Administration (NASA) has been a pioneer in the use of telemetry of medical data to track the well-being of astronauts in space and has a long history of interest in telemedicine. NASA applied lessons learned in space (5) to a demonstration project entitled "Space Technology Applied to Rural Papago Advanced Health Care," or STARPAHC, that served the Papago Indian Reservation in Arizona during a period in the 1970s. The project received mixed reviews for cost and practicality.

NASA has remained steadfast in its interest in telemedicine and has continued to help advance the field. NASA successfully undertook a recent demonstration project (6) in the use of ultrasonography (US) on the International Space Station. Astronauts with minimal training in imaging examined each other's shoulders under direction from sonologists at NASA's Telescience Center in Houston, Tex, with images transmitted back to Earth for review.

Teleradiology systems became commercially available in the 1980s from a number of vendors but, in retrospect, were very limited in quality and scalability. So-called camera-on-a-stick systems enjoyed a brief vogue mostly for hospital-to-home applications to provide "after-hours" coverage. The approach entailed photographing or videographing selected hard-copy images for subsequent digitization and image transfer. More sophisticated systems used laser-based digitizers for the same purpose, but both approaches were cumbersome—images were handled one at a time—and these systems were rapidly eclipsed by later advances in technology. In sum, for teleradiology up to the early to mid-1990s, the relatively low performance and high costs of available computer systems, high costs of data transmission, and lack of practical and affordable digital image handling systems (including high-resolution workstations at originating and receiving sites) continued to block widespread adoption of the approach.

The technology factors holding back teleradiology all changed dramatically (7,8) in the past 10–12 years with the introduction of lower-cost communications systems such as the Internet, incredible improvements in price versus performance for computers, and wide adoption of picture archiving and communications systems by radiology practices. In the same time frame, medical imaging underwent a transformation from image recording and viewing on film images to the potential for direct digital capture and computer workstation viewing of images from all modalities. Taken together, these advances have provided a practical and affordable platform for implementing teleradiology.

These advances also allayed questions about degradation in the quality of transmitted images (3) that were the subject of extensive study and debate as long as conventional radiographs were being secondarily digitized to permit image transmission and the analog-to-digital conversion of video signals was being used for capture of images from computed tomography (CT) and magnetic resonance (MR) imaging. Data compression is another enabling technology (3,9) that remained somewhat controversial until advanced compression methods such as wavelet-compression became available.

The rapidity and importance of the technologic progress supporting teleradiology is well illustrated in some of our early efforts at Massachusetts General Hospital (MGH). When we first established a teleradiology link between Riyadh, Saudi Arabia, and MGH in 1994, it took over 1 week of effort by two engineers sent from the United States to assemble the special proprietary equipment that had to be shipped in by air freight. Establishing the communications link required working with the local telephone provider. The communications link consisted of four multiplexed voice-grade phone lines yielding a transmission rate of less than 40 kilobits/sec. At this rate, it took 2–5 minutes to transmit conventional radiographs digitized at a matrix resolution of 1664×2020 with 12-bit pixels and compressed at an average ratio of 23:1. The equipment and software were all proprietary and cost over $100 000.

Only 3 years later when we established a teleradiology service between a hospital in Istanbul, Turkey, and MGH, the hospital in Istanbul simply purchased a personal computer and film digitizer on the local market, and a transmission pathway was established over the Internet in about 2 hours of telephone conversation and testing by engineers working together at each site. Today, the combination of direct digital capture capability in radiology, the widespread adoption of picture archiving and communications systems, the availability of low-cost personal computer–based workstations, and advances in data compression and transmission methods make it almost trivially easy to establish teleradiology links between sites.

Legal Issues and Practice Standards

Prior to 1990, telemedicine applications, including teleradiology, were relatively unimportant and largely ignored by state practice of medicine statutes or professional societies. In 1994, the American College of Radiology (ACR) published the *ACR Standard for Teleradiology* (10). In this technical standard, the ACR stated that physicians providing official interpretations with teleradiology methods should maintain licensure at both the initiating and receiving sites and should hold staff credentials if a hospital was the originating site of an examination.

In 1996, the Federation of State Medical Boards (11) developed a "model act" to address the practice of medicine across state lines. Physicians would apply for a special license for telemedicine to be issued by the state medical board with jurisdiction over the initiating or sending site. Further, such license would only be required if such practice were "regular and frequent," as defined by the respective boards. If telemedicine practice constituted less than 1% of a physician's practice, occurred less than once a month, or involved fewer than 10 patients per year, no license would be required. This model statute gained no traction and was roundly ignored by the states.

Rather than pass new regulations to facilitate the interstate practice of telemedicine, most states (11) have added restrictions and have made their statutes more specific with respect to telemedicine services and generally require licensure if services are provided to their citizens. A few states have exceptions for emergency services or infrequent services and the majority have exceptions for consultations between providers. State medical societies have generally lobbied for more, rather than fewer, restrictions on telemedicine and probably view such services as an economic threat.

In this age of ubiquitous telecommunications and access to knowledge, it seems backward to make it more difficult, rather than easier, to serve patients by using telemedicine methods. The usual rationale for restricting interstate practice is the hegemony of the states over medical practice and therewith their responsibilities to oversee the quality of services provided to their populations. Licensure is a major quality filter and point of accountability and quality control. If no license were required for providing services across state lines, a state medical board might not be able to restrict a deficient or impaired practitioner and might encounter difficulty with oversight in general. The counterargument is that the states have substantially the same requirements for licensure and could come to a working agreement on how to deal with issues such as impaired physicians. What is missing from the actions of the respective states is the point of view of patients who effectively are being restricted in accessing care from experts in out-of-state locations, which is counter to the promise and culture of the information age.

In current practice, radiologists typically obtain a medical license for every state from which they receive images and provide interpretations by using teleradiology methods, in keeping with the standards posited by the ACR (10) that also call for them to be licensed in the state in which the interpretations physically take place. Likewise, radiologists become credentialed in each hospital for which they provide service. Radiologists living abroad and offering international teleradiology services to patients in the United States follow these same principles, although the ACR has developed a position paper for international teleradiology (12) that takes into account the fact that state licensure for overseas radiologists is obviously moot at their location on the receiving end of the teleradiology services.

The need for licensure in each applicable state and hospital has led to enormous traffic in paperwork, as large commercial and practice-based teleradiology businesses are being established. For example, we have received requests for over 100 licensing and credentialing attestations on behalf of a former trainee who works for an overseas teleradiology services company.

Equipment that is used in teleradiology systems and is available commercially must receive approval from the Food and Drug Administration. Beyond that, there are no legal standards for the technology used in teleradiology either within states or between states. Most practices follow the ACR Technical Standard for Teleradiology, which calls for maintaining the integrity of the image data and for viewing images at the same or higher resolution compared with the resolution used to acquire the original images.

Reimbursement for telemedicine is a patchwork quilt between payers. However, teleradiology is almost universally reimbursed, probably under the rationale that radiology interpretive services are typically not provided with the radiologist face-to-face in the presence of the patient. Interestingly, the Center for Medicare and Medicaid Services (CMS) does not even consider teleradiology (13) to be a telemedicine service and has consistently provided reimbursement for both intrastate and interstate teleradiology services.

According to the CMS (13), "A service may be considered to be a physician's service where the physician either examines the patient or is able to visualize some aspect of the patient's condition without the interposition of a third person's judgment. Direct visualization would be possible by means of x-rays [radiographs], electrocardiogram and electroencephalogram tapes, tissue samples, etc. For example, the interpretation by a physician of an actual electrocardiogram or electroencephalogram reading that has been transmitted via telephone (ie, electronically rather than by means of a verbal description) is a covered service."

While the CMS may be regarded as forward looking in its definitions, no reimbursement is provided by the CMS for medical services provided outside of the United States. This is historically reasonable to prevent unregulated out-of-country providers from billing for services, but it does not make sense otherwise in light of the CMS's own stance on teleradiology, especially if the international radiology provider is licensed and credentialed in the jurisdiction of the patient.

Teleradiology Applications

In the era before the widespread use of CT and US to evaluate patients presenting in the emergency room, many radiologists expected their emergency physician colleagues to review the images from conventional radiography studies they ordered for their patients off-hours and to take responsibility for a provisional interpretation. Radiologists then provided the official interpretation the next morning. I observed this as a radiology resident providing off-hours coverage for my own institution and as an evening "moonlighter" for a number of other practices in the Washington, DC, area in the early 1970s. Suspected fractures and pneumonias were the most common indications for emergent radiography. After on-site coverage ended at 11:00 PM, physicians covering the emergency room reviewed the radiographs and radiologists were called in only for difficult cases or for contrast material–enhanced studies, fluoroscopy, angiography, or nuclear scintigraphy. Otherwise, radiologists hoped to be able to sleep through the night. Exploratory surgery ruled the day for head trauma, nonskeletal trauma, and the acute abdomen. Patients suspected of having pulmonary embolism might be administered a dose of heparin pending a ventilation-perfusion scintigraphy examination in the morning.

All of this changed dramatically with the recognition that exploratory surgery could be virtually eliminated by applying imaging methods—most importantly, CT and US. At this juncture, emergency physicians were no longer comfortable "going it alone" because of the complexities of interpreting CT scans versus conventional radiographs, and radiologists have been scrambling ever since to respond in ways that meet the service needs and expectations of referring physicians and patients while preserving a reasonable work life for themselves.

One obvious answer has been teleradiology. The use of teleradiology eliminates the need to travel from home to the hospital and can be used to consolidate calls between multiple locations. It is a strategy that radiologists have widely adopted to meet the changing needs of their practices.

In a 1999 survey of radiologists in the United States, Larson et al (14), found that 75% of responding multiradiologist practices and 30% of solo practices used teleradiology. In 92% of the former practices, radiologists used teleradiology to provide preliminary on-call interpretations. The most commonly reported modality covered through teleradiology was CT, at 95%, followed by US, at 84%. Conventional radiography was cited in only 43% of responses and MR imaging in 47%. In another survey of 114 private hospitals reported by Saketkhoo et al (15), among the 97 responding institutions, 82% reported the use of teleradiology for nighttime coverage. The data from these surveys indicate that radiologists in the United States have embraced teleradiology and, by inference, must believe that it meets necessary requirements for accuracy and timely service.

The use of on-call teleradiology for interpretation of images from off-hours examinations has continued to increase, due in part to the activities of a number of commercial enterprises founded specifically to provide outsourced off-hours coverage for radiology practices but also due to some academic and private practices that have begun offering substantially similar services. Within the Partners HealthCare System in Boston, Mass, both the Massachusetts General Hospital and the Brigham and Women's Hospital departments of radiology offer nighttime teleradiology coverage services. Both departments have their own internal 24-hour-per-day coverage teams and take advantage of that service to help smaller facilities in the region by providing teleradiology coverage.

Hundreds of hospitals and radiology groups have taken advantage of the services of outsourcing companies or other radiology groups to provide and maintain timely radiology coverage for their institutions and to make better use of their own manpower while maintaining a reasonable work life. Advertisements for radiologists to join groups now often include specific reference to whether the group has such nighttime coverage.

The term *nighthawk* has entered the radiology lexicon to reference radiologists providing on-call coverage whether that coverage is provided internally by a group member dedicated to that purpose or to an employee of an outsourcing company. The same term is used to reference companies providing on-call services.

Data on the prevalence of other applications of teleradiology beyond nighttime coverage are not available, but it is clear that the same enabling factors that have facilitated the use of teleradiology for on-call coverage also apply more generally. Many practices, including ours at Massachusetts General Hospital, are taking advantage of those enabling factors to create new practice models (8). We have established a distributed practice model that allows subspecialist radiologists to work remotely from the main hospital in community-based imaging centers and interpret studies in their respective areas of expertise originating from multiple locations within the Massachusetts General Hospital system in an efficient way. We have also undertaken responsibility for covering a number of small outside practices that are without staff, understaffed, or have limited subspecialty expertise. We are using the same technology to support members of our faculty who need to live remotely for periods of time, such as a staff member who accompanied his or her spouse while he or she undertook fellowship training overseas.

It is highly likely that the application of teleradiology to routine daytime practice will now rapidly increase since it affords a means of more efficiently matching the supply of radiologists with demand for their services than can be achieved through the distribution of radiologists on the basis of their physical presence in different practice locations—especially when complex subspecialty studies are involved. One radiologist can potentially cover a number of locations where there might not be enough work for a full-time radiologist, and one subspecialist can potentially provide consultations for patients in many practice locations. Academic centers are likely to be approached to make their subspecialty expertise more available. The commercial companies nominally founded to provide on-call nighthawk services are also moving assertively in this direction, and the descriptive term *day hawking* has now also entered the radiology lexicon.

As the current trend continues toward more radiology being practiced remotely, it will promote and facilitate a substantial consolidation of providers into larger organizations whether they are radiology professional practice groups or commercial companies. Hospitals looking for better performance or more accountability in their radiology operations will turn to these entities and contract with them to manage their radiology departments. Smaller groups working in a generalist model of practice will be challenged to provide access to subspecialists and will face difficult decisions about whether to work with others or risk losing their franchises as their specialist colleagues in other disciplines demand more expertise in interpretation of imaging studies.

Teleradiology is poised to play an important role in peer review and quality assurance. With the Joint Commission on Accreditation of Healthcare Organizations pushing for more evidence of performance evaluation between credentialing events, radiology groups will need to develop better systems for assessing the accuracy of their work and for peer review. In some settings, radiologists are being challenged by their physician colleagues and their institutions to more objectively demonstrate the quality and accuracy of their interpretations. The use of teleradiology can facilitate groups working together in reciprocity to review each others work or to contract with outside organizations to address these quality issues.

Education in all medical disciplines has already been indelibly changed by telecommunications. Again, radiology is a leader because of the fidelity and flexibility of digital image management. Teaching files are available from national and international sources on the Internet, as are Web casts of lectures, case-of-the-day presentations, and teaching conferences. Travel is no longer necessary to access outstanding learning opportunities, although tele-education falls short on direct person-to-person mentoring, which provides tangible and intangible aspects that we should not undervalue.

Research in radiology is being transformed through teleradiology in parallel with clinical practice. Image data from clinical trials can be collected faster and more efficiently by direct digital transfer than by shipping hard-copy film records. The ACR Imaging Network has secure connections to over 100 hospitals supporting data collection in 20 or more active trials (16,17). The pharmaceutical industry has discovered the value of imaging biomarkers for use as end points in clinical trials and will undoubtedly drive further network development.

Conclusion

Several factors—including the prevailing shortage of radiologists, the increasing use of advanced imaging methods, the consolidation of hospitals into regional delivery systems, and heightened expectations of patients and referring physicians for timely service—have fostered the increasing use of teleradiology. These factors have also helped underwrite the creation of new and potentially disruptive business models for service delivery that can be viewed as threats, opportunities, or both, but cannot be ignored.

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