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 applica-
In the 1970s and gaining momentum in the 1980s, attention turned to computer-based approaches to teledemi-
cine, 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 initiat-
ing site and are aggregated and stored
for subsequent transmission to a receiv-
ing site. The store-and-forward ap-
proach simplifies operations by elimi-
nating 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 di-
rect televised face-to-face or voice con-
tact between patients and providers can
be used to deliver the service. Other
services provided in this way include
teleradiology, telepathology, inter-
pretation of electrocardiograms, and
home monitoring of patients (ie, mea-
surement of heart rate, blood pressure,
and weight).

The National Aeronautics and Space
Administration (NASA) has been a pio-
near in the use of telemetry of medical
data to track the well-being of astron-
auts in space and has a long history of
interest in telemedicine. NASA applied
lessons learned in space (5) to a demo-
stration project entitled “Space Tech-
ology Applied to Rural Papago Ad-
vanced Health Care,” or STARPAHC,
that served the Papago Indian Reserva-
tion in Arizona during a period in the
1970s. The project received mixed re-
views for cost and practicality.

NASA has remained steadfast in its
interest in telemedicine and has con-
tinued to help advance the field. NASA
successfully undertook a recent demon-
stration project (6) in the use of ultra-
sonography (US) on the International
Space Station. Astronauts with minimal
training in imaging examined each oth-
er’s shoulders under direction from so-
ologists at NASA’s Telescience Center
in Houston, Tex, with images transmit-
ted back to Earth for review.

Teleradiology systems became com-
mmercially available in the 1980s from a
number of vendors but, in retrospect,
were very limited in quality and scalabil-
ity. So-called camera-on-a-stick systems
enjoyed a brief vogue mostly for hospi-
tal-to-home applications to provide “af-
ter-hours” coverage. The approach en-
tailed photographing or videographing
selected hard-copy images for subse-
quent 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 technol-
ogy. 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 sys-
tems (including high-resolution work-
stations 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 communica-
tions systems such as the Internet, in-
credible improvements in price versus
performance for computers, and wide
adoption of picture archiving and com-
munications systems by radiology prac-
tices. 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 worksta-
tion viewing of images from all modal-
ities. Taken together, these advances
have provided a practical and affordable
platform for implementing teleradiol-
y.

These advances also allayed questions
about degradation in the quality of trans-
mitted images (3) that were the subject of
extensive study and debate as long as con-
ventional radiographs were being second-
arily digitized to permit image transmis-
sion and the analog-to-digital conversion
of video signals was being used for cap-
ture of images from computed tomogra-
phy (CT) and magnetic resonance (MR)
imaging. Data compression is another en-
abling 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 teleradi-
ology is well illustrated in some of our
early efforts at Massachusetts General
Hospital (MGH). When we first estab-
lished a teleradiology link between Ri-
yadh, 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 equip-
ment that had to be shipped in by air
freight. Establishing the communica-
tions link required working with the lo-
cal telephone provider. The communi-
cations link consisted of four multi-
plexed voice-grade phone lines yielding
a transmission rate of less than 40 kilo-
bits/sec. At this rate, it took 2–5 min-
utes to transmit conventional radiogra-
phs digitized at a matrix resolution
of 1664 × 2048 with 12-bit pixels and
compressed at an average ratio of 23:1.
The equipment and software were all prop-
rietary and cost over $100,000.

Only 3 years later when we estab-
lished 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 Inter-
net in about 2 hours of telephone conver-
sation and testing by engineers working
together at each site. Today, the combi-
nation of direct digital capture capability
in radiology, the widespread adoption of
picture archiving and communications
systems, the availability of low-cost per-
sonal computer–based workstations, and
advances in data compression and trans-
mision methods make it almost trivially
easy to establish teleradiology links be-
tween sites.

**Legal Issues and Practice Standards**

Prior to 1990, telemedicine applica-
tions, including teleradiology, were rel-
atively 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 Teleradi-
ology* (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 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 administrated 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 Saketkoo 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 night-hawk 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.

References

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