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The Future of Teleradiology in Medicine Is Here Today

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Abstract Teleradiology is transferring of medical images through an Internet provider from a primary system to a remote location. Compressed digital imaging tools and the picture archiving and communication system have helped teleradiology to become more accessible and feasible to physicians. Wireless transmission using portable viewers has the potential to further improve its application and accessibility. In order to protect confidential medical records from being accessible to unauthorized individuals, security measures such as the establishment of a virtual private network between hospitals and receiving locations have been taken. Teleradiology provides students, residents, and even attending physicians with access to a limitless number of images for reference from almost anywhere in the world and helps improve their continued exposure and experience in the health-care setting.

2.1 Introduction

Teleradiology is the practice of transferring medical images electronically through an Internet provider from a primary system to a remote location for the diagnosis or treatment of patients. With the widespread availability of the Internet today, the sharing of medical imaging between physicians has become more commonplace. Smaller medical practices in rural communities can now share knowledge and resources with larger health-care providers in urban settings without changing locations. Magnetic resonance images, computed tomography (CT) images, angiograms, and even classical X-rays can be transferred electronically in a matter of seconds to minutes from one health provider to another. As a result, medical images can easily be shared within the same facility, between facilities of the same practice, between physicians of different practices, or even from the hospital to the home of a physician via a computer. Furthermore, consulting and treating physicians can access films at any location with

Internet connections, and, with the growing availability of wireless Internet, teleradiology access has become nearly unlimited. While physicians of all medical specialties may soon incorporate some aspect of the field into their daily work, currently radiologists most commonly utilize teleradiology in their practice. In order to demonstrate the use of teleradiology, the American College of Radiology (ACR) poled radiologists in the years 1999 and 2003 to determine how prevalent the use of teleradiology was among radiologists [4]. The data showed an increase in use over time from 1999 to 2003. There were also significant differences between the types of practices and the use of teleradiology. Academic practices, rural-setting practices, and practices with a larger number of radiologists tended to utilize teleradiology at a higher prevalence than other practices. From these data, one can infer that teleradiology is a significant advancement used in education and to improve patient care.

2.2 History: The Beginning

With the advent of the Internet in the early 1990s, teleradiology was born. One of the primary obstacles in the development of teleradiology was the conversion of analogue images into digital formats, in order to facilitate the transfer of images via the Internet. Before the digital age of the digital versatile disk, medical images were primarily stored in analogue format [physical quantity (electric)]. In order to transmit these pictures via the Internet, these images needed to be converted to a digital binary code [(0,1)]. The primary problem with digital conversion was that these documents occupied a large amount of pixel storage and size. In order to have maximum resolution and to provide clear pictures, the images require a great number of pixels, which in turn results in larger file sizes and corresponding transmission times. For example, the ACR recommends that small matrix size radiographs (such as from MRI, CT, ultrasound nuclear medicine, digital fluorography, and digitized radiographic films) should provide a minimum matrix size of 512 × 512 (0.26 megapixels) at a minimum 8-bit pixel depth (color depth). Similarly, ACR recommendations for large matrix size radiographs (including those from digital radiography and digitized radiographic films, i.e., scanned X-rays) should provide a minimum of 2.51 pixel/mm special resolution (approximately 4.0 megapixels) at a minimum of 10-bit pixel depth [2]. Thus, scanned X-ray files can be quite massive and exceed 1 MB in size. This creates transfer difficulties when the standard Internet connections can only maximally upload a file at a speed of less than 1 kbps. This would require 30 min to upload one image at a time and an additional 20 min to download the image from the Internet to a remote computer.

In order to overcome long transfer times, image compression of digitalized files into a Joint Photographic Experts Group (JPEG) file or Graphics Interchange Format (GIF) was devised. JPEG and GIF files are typically compressed at ratios of 20:1 and 10:1, respectively [15], without losing any resolution. Thus, digital images can be compressed in JPEG format or GIF down to more manageable sizes of 20–100 kB, respectively, and this leads to a decrease in subsequent transfer times.

In addition to the creation of compressed digital imaging tools, the development of the picture archiving and communication system (PACS) has also helped circumvent the analogue to digital problem in the storage of medical images. The PACS allows digital storage of medical images, thus making the transfer of images to a remote location much more efficient and eliminating the need for analogue file conversion. Today, magnetic resonance images, CT, images, angiograms, and ultrasound images are now all commonly stored in a digital format directly into the PACS. In addition, plain X-ray films are similarly stored in a digital format with the PACS to avoid scanning analogue films into a digital format.

2.3 Future Goals and Benefits

The contributions of compressed digital imaging tools and the PACS have allowed the field of teleradiology to become more accessible and feasible to physicians. Given the wide array of potential uses, the ACR has established goals for incorporating teleradiology into daily medical practice. With each goal, a potential benefit to the radiologist and other treating physicians exists. These goals are primarily focused on improving patient care through an increased networking among physicians in order to reach a conclusive diagnosis (Table 2.1).

2.4 Technical Framework: Backbone for Teleradiology

The technical framework of the Internet serves as the backbone for teleradiology. The rate-limiting step in teleradiology is the speed at which data can be transferred. In 1990, the first medical images were sent via a dial-up service over standard phone lines at the University of Kansas Medical Center [13]. At that time, the maximum capabilities of the dial-up server were download speeds of 56 kbps over a standard phone line. Soon after, the new technology of digital subscriber lines (DSL), initially developed by Joe Lechleider of Bellcore in 1988, began to have increased utility in data transfer. DSL increased the

Table 2.1. A list of goals set forth by the American College of Radiology (*ACR*) for the advancement of teleradiology and the benefits of each [2]

ACR goals for teleradiology	Benefits
1. Provide access for consultation and interpretation of films from peripheral locations	Allow for second opinions from physicians at offsite locations and/or opinions from subspecialties of radiology
2. Provide radiologic support in health facilities without a radiologist	Underserved rural communities gain access to radiologists throughout the world
3. Provide immediate radiologic image interpretation for both nonemergent and emergent patient care	Saves time and decreases the risk of misplacing or losing images by avoiding mailing hard copies of images. Furthermore, the radiologist can access images from home computers, PDAs, or even phones to provide information back to treating physicians
4. Return interpreted images back to referring providers	Interpreted images are efficiently returned to the primary-care or emergency-room physician
5. Improved interpretation	Traveling imaging centers can relay their information directly to a major medical center where image reading can be overlooked by a number of physicians. This will decrease the time needed to interpret images in addition to decreasing the number of misdiagnosed patients owing to error with image interpretation
6. Teleradiology supports telemedicine	Instead of explaining an image or finding, the image can be sent directly to a corresponding physician
7. Sharing and availability enhance educational for practicing radiologists	As new information and data come out, it will be more efficient for physicians to become educated via image transfer with teleradiology

PDA personal digital assistant

speed of data transfer by relying on existing copper phone lines and now provide maximum rates of 6.0 Mbps [3]. Although traditional voice signals travel over phone lines on a very limited range of frequencies, local telephone cables can carry signals at frequencies well above and below the frequencies used for phone calls. DSL use the advantage of these unused frequencies to transmit data. In the mid-1990s, the new development of cable broadband became available and pushed data transfer rates even faster (currently a maximum of 30 Mbps) [11]. The drawback to cable Internet is that it is a "shared" network, and multiple subscribers are feeding from the same source. Thus, during peak usage, cable Internet providers do not provide transfer speeds anywhere near their advertised capabilities. More recently, the advent of bundled copper lines came into use with T1 and T3 cables. The advertised speed capabilities with these modalities are up to 1.5 Mbps [3] for T1 connections, and newer T3 cables allowed speeds of 45 Mbps [3]. Thus, using a T3 broadband at a speed of 45 Mbps, one can upload and transmit a CT scan with a size of 100 Mb in only 2.2 s. Although fast, this transfer rate is well below the maximum capabilities of 9.08 Gbps, which would make transmission nearly instantaneous (University of Tokyo) [9]. These speeds are accomplished via fiber-optic technology, which uses a thin glass tube and light impulses to propagate a signal. These light impulses have much higher speed capabilities than the previously mentioned copper wire connections. Therefore, newer technologies are continually being sought to increase the speed of data transfer.

The most recent development in data transfer tools has been the use of wireless technology. In the early 1990s, wireless data transfer began to surface, and in 1995 Yamamoto [17] reported the first use of wireless radiologic data transfer. Wireless networks use both radiofrequency and microwaves for data transfer as opposed to hard-wired lines composed of copper or fiber-optic cables. The most common form of wireless network can be found at local coffee shops and airports and is referred to as a wireless local-area network, which conforms to the 802.11 Wi-Fi standards (microwave frequency) [5]. The signals used by wireless Internet connections are similar to that used in cellular phones. Cellular phones transmit radiofrequency signals to a base tower, which in turn can relay the signal. Different frequencies are used to send a signal back to the phone from the tower to limit interference. These "wireless" signals are ultimately linked to the hard-line phone network by base towers that relay data directly to the hard-wired network (fiber optic or copper). Thus, the wireless network is composed of both radio and microwave signals, which are connected to hard-wired lines by large (cellular network) or small antennas. With the advent of wireless technology, the current maximum data transfer speed of 72 Mbps [current potential of Worldwide Interoperative Microwave Access (Wi-Max) technology] [17] is dramatically faster than the 56 kbps achieved over standard phone lines. However, typical of all wireless technology, the maximum data stream is a function of distance from the nearest base station. Therefore, the maximum speeds of Wi-Max and other wireless technology [Evolution Data Optimized (EVDO) and High-Speed Downlink Pocket Access (HSDPA)] are not representative of their practical capabilities.

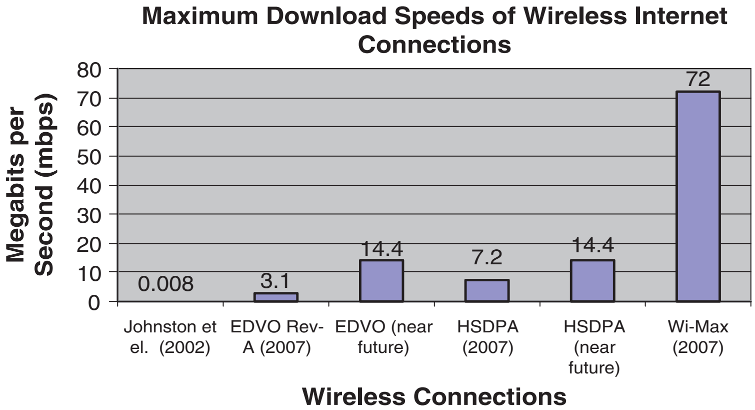

Fig. 2.1. Download capabilities of past, present, and future wireless Internet connections. The Cingular network is very metropolitan based and the Wi-Max network basically is a work in progress in the USA (started in Russia)

Wireless transmission using portable viewers has the potential to further improve the application and accessibility of teleradiology. In 2005, Johnston et al. [10] demonstrated that images of renal colic with obstructing kidney stones or renal trauma cases could be transmitted through a simple wireless personal data assistant (PDA) connection and received for interpretation [16]. The download capability of wireless at that time was only 1 kbps (PDA through phone). However, download speeds have become faster as the technology in portable wireless units has improved. The new HSDPA (Cingular Wireless, Chicago, IL, USA) is capable of reaching download speeds of 7.2 Mbps (Fig. 2.1) [7]. This 3G technology was recently released in 2005 and is the first wireless technology that allows simultaneous voice and data streams. By providing separate channels for data transfer, the downloading of a Web page on the data stream is not interrupted by the voice stream if there is an incoming call. Presently, HSDPA is only available in 18 large metropolitan markets in the USA. Code Division Multiple Access–EVDO, a more commonly available 3G technology (Sprint and Verizon), was released in the USA in 2002, and is the primary wireless access found in urban settings across the world (Europe and Asia). Recently, EVDO-carrying companies have been upgrading to an EVDO Rev A product, which can match the speeds of HSDPA and also offers simultaneous voice and data streams. Further applications of teleradiology can be expected as the improvements in portable wireless units maximize the potential data transfer rates already achieved by wireless signaling.

In addition, portable wireless viewers may also use mobile satellite providers, such as Inmarnet's Broadband Global Area Network, for data signaling. Using satellite providers, global data coverage in wireless signaling is almost limitless with only small deficiencies in coverage at the polar ice caps [8]. The maximum download speed for some satellite providers is approximately 2 Mbps [1]. Unfortunately, like any satellite technology, weather can interfere with the signal transmitted to and from the receiver, thus decreasing expected download speeds.

2.5 Teleradiology Security and Preservation of Confidentiality: How Health Providers Maintain Confidentiality with the Electronic Transmission of Patient Records

The issue of patient confidentiality and Internet security arises whenever medical data are sent over the Internet. Because of the concern that unauthorized individuals may be able to obtain access to confidential medical records during transmission, a secure connection must be established from hospitals to the external remote location. Currently, the most widely used security measure among teleradiology services involves the establishment of a virtual private network (VPN) between hospitals and receiving locations [14]. A VPN provides a secure connection via the Internet, which mimics a private point-to-point connection. Employees on the road or at home may connect in a secure fashion to the corporate network via public access. All images and data sent over a VPN are encrypted. In order for physicians to decipher and view the medical images, they must enter a code from an encryption key that is personalized to each physician. Each key is updated and changed frequently. Therefore, data intercepted by hackers on a public or shared network are not interpretable unless they have access granted through the encryption keys. For security reasons, a VPN must also provide audit and accounting records to show who has accessed what information at what time. In doing so, medical images, as well as medical information, can be sent in a secure manner over a public network with verification of the intended viewer.

2.6 Education and Training: Increasing the Knowledge of Physicians with Increased Image Exposure

The ability for physicians to share images quickly and cost-effectively over the Internet allows for the continuing education throughout the medical community. Teleradiology provides students, residents, and even attending physicians with access to a limitless number of images for reference from almost anywhere in the world. Health-care providers treating rarer medical ailments have the ability to utilize the data banks or physicians' expertise from more endemic areas. In doing so, all physicians can improve their continued exposure and experience in the health-care setting and further develop subspecialized areas of interest or expertise if desired without changing locations. For example, a radiologist could become an expert in reading hand films. He or she may receive inquiries via teleradiology for consultations, second opinion, and/or confirmation of prior interpretations from a physician with less experience in hand pathology. As a result of this interaction, both physicians will benefit—either by gaining more experience with specialized diseases or by direct expert opinion in nonendemic areas.

2.7 Future Directions: Where Wireless Communications Could Take Teleradiology

Wireless connections are becoming increasingly available throughout the world. Satellite broadband is accessible in most countries and access plans through cellular phone providers are not far behind. In 2007, the number of cellular phone users passed the three billion mark [6]. In addition to availability, the speed of wireless technology is ever-increasing. Once a technology reaches its maximum capability, another technology appears to replace it. Once EVDO and HSDPA reach their respectable maximum download speeds (Fig. 2.1) [7, 12], the new technology Wi-Max (4G technology) will likely be out of its infant stage and have increased availability throughout the world. Wi-Max is a new wireless technology service being adapted by most industrialized nations. It is similar to Wi-Fi (common wireless networks at coffee shops, colleges, and airports), with the added ability to be broadcast over a much larger area of interest (up to 30 miles). For example, Korea Telecom is in the process of deploying its version of Wi-Max (WiBro) throughout the entire city of Seoul, South Korea. Its network will assist in the signal control of subway transportation and has speeds of up to 1–3 Mbps. Intel (via Australia's Unwired) and Sprint/Nextel have already predicted that Wi-Max will eventually replace many hard-wired communication services with upper limits of Wi-Max Internet connection of 72 Mbps (Fig. 2.1).

Overall, the primary goal of teleradiology is to provide improved health care to patients by expediting disease diagnoses with quicker and more specialized interpretations of medical images and data. In addition, physicians will have more exposure to large databases of radiological images in which to familiarize themselves, in order to bring the best possible diagnostic skills to patients. Wireless teleradiology will aid in the treatment of emergency cases or when a specific specialist must be reached outside of the work place both locally and worldwide. Health-care providers in remote regions of the world with poor hard-line Internet capabilities will benefit most from wireless teleradiology, by bridging potential deficiencies in medical image interpretations and consultations. Despite increased resources, even industrialized countries will benefit from wireless teleradiology, as certain modalities such as MRI are not readily available at every hospital and a traveling MRI machine must be utilized for nonemergency patients. Wireless broadband would be ideal for these machines, if a situation arises when interpretation must be made from a remote location. Thus, wireless teleradiology can bridge the gap and better equalize health-care knowledge in all different settings.

2.8 Conclusion

The ability to transmit information worldwide through an almost instantaneous Internet connection is before us today. Teleradiology allows the sharing of medical images between different health-care professionals and improves care of patients. Its role in medicine will increase exponentially as transmission speeds continue to improve.

Summary

- Teleradiology is transferring of medical images through an Internet provider from a primary system to a remote location.
- Compressed digital imaging tools and the PACS have helped teleradiology to become more accessible and feasible to physicians. Wireless transmission using portable viewers has the potential to further improve its application and accessibility.
- In order to protect confidential medical records from being accessible to unauthorized individuals, security measures such as the establishment of a VPN between hospitals and receiving locations have been taken.
- Teleradiology provides students, residents, and even attending physicians with access to a limitless number of images for reference from almost anywhere in the world and helps improve their continued exposure and experience in the health-care setting.
- The primary goal of teleradiology is to provide improved health care to patients by expediting disease diagnoses with quicker and more specialized interpretations of medical images and data.

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