Real World Teleradiology

Frank Earnest IV

TELERADIOLOGY presents both opportunities and challenges for the organization, delivery and regulation of healthcare. Telecommunication technologies can improve healthcare access for rural and underserved communities, improve access to subspecialty care, and expedite delivery of needed services. Teleradiology is likely to stimulate competition and may result in cost reduction by more efficient use of healthcare personnel.

The term teleradiology only partially conveys the management and interpretation of electronic images over a wide area network (WAN) using remote dial-up communications. In practice, electronic imaging on a campus-wide network (using a picture archiving and communication system or PACS), and electronic imaging over a WAN are blending into a single system.

There are numerous issues to be considered in using this including technical issues and requirements, clinical requirements, and socioeconomic practice concerns. Teleradiology is often viewed as a source of predatory competition from entrepreneurial radiologists seeking to displace local providers. The legal ramifications of what services are provided (official interpretation versus second opinion), to whom they are provided (requested from patient versus requested from licensed physician), and cross-jurisdictional issues will be the focus of Mr. Whelan's presentation in this issue.

TECHNICAL REQUIREMENTS

Current technical specifications for teleradiology have been arbitrarily based on current hardware capabilities and our limited understanding of the physiology and psychology of image interpretation. Lesion detection and the effects of image enhancement and compression are under intense investigation.

A current list of requirements for the "ideal electronic imaging system" would include:

- (1) Low cost
- (2) Support of both network and dial-up communications
- (3) Variable, high level compression
- (4) Digital Imaging and Communications in Medicine (DICOM) image format
- (5) Multiple data sources—original image data (eg, computed tomography [CT]), digitized film, computed radiography, video frame grab
- (6) Open architecture
- (7) User-friendly software at sending and receiving sites
- (8) High resolution workstation with bright monitors (>120 ft. Lamberts)
- (9) Integration with image management/RIS
- (10) Supports bidirectional image transmission and interpretation

CLINICAL REQUIREMENTS AND VALIDATION

The electronic imaging and teleradiology literature in major, peer-reviewed journals contains studies that differ in many parameters. These differences include:

- (1) Methodology (prospective sequential comparative study,^{1,2} receiver operator character analysis,³⁻¹¹ phantoms,^{12,13} animal models¹⁴)
- (2) Type of images studied (chest,^{3,6,10} skeletal,^{2,4,5,8,9,11,15} GU,¹⁶ emergency radiography^{9,15}).
- (3) Imaging modality (computed radiography,^{2,4-8,10,12,13} digitized film^{1,3,9,11,15-18})
- (4) Acquisition, processing, display (matrix of acquisition and display, image post-processing)
- (5) Data analysis, results, and conclusions

Studies that compare the diagnostic accuracy of conventional x-rays and the same images after conversion to a digitized image (using a film digitizer or charge coupled device) generally report inferior diagnostic accuracy for the digitized film images. This diagnostic inferiority is apparent in identification of subtle abnormalities on emergency examinations⁹ or subtle fractures.^{11,15}

The scientific evaluation of electronic imaging is

From the Department of Diagnostic Radiology, Mayo Medical Center, Rochester, MN.

Address reprint requests to Frank Earnest IV, MD, Department of Diagnostic Radiology, Mayo Medical Center, Rochester, MN 55905.

*Copyright © 1997 by W.B. Saunders Company
0897-1889/97/1003-1008\$3.00/0*

becoming more sophisticated and the quality of electronic images is constantly improving. The ability to adjust image contrast (window and level image data) and to modify the processing of image data to emphasize certain characteristics (edge enhancement, etc) provides distinct advantages over conventional screen film radiography. There are some drawbacks related to the flexibility of computed radiography image display. Because of the many display variables, diffuse abnormalities (interstitial changes in the lung, osteopenia in the skeletal system) may be difficult to recognize.

Image compression is necessary for practical teleradiology communications over existing telephone lines (POTS, ISDN). Transmission of plain chest radiographs can take up to 1 hour over a phone line using a high speed modem without lossy compression. Newer lossy compression techniques using a wavelet transform have been validated for chest radiography at our institution and show no qualitative loss in diagnostic information to at least a ratio of 40:1. Skeletal radiographs may be less tolerant of compression.

COST

There is no additional cost to convert CT, magnetic resonance imaging (MRI), ultrasound (US), or nuclear images into digital computer files because that is how they are initially acquired. Most current CT and MRI images use DICOM format/communications and can directly send images files to a DICOM teleradiology transmission system. Newer US imagers are using DICOM format/communications as well (eg, GE, Siemens). DICOM is not currently used by nuclear imaging equipment. Typical low-cost teleradiology systems use digital "frame grab" technology that captures a video image through video output. These frame grab systems reproduce the image displayed on the monitor from any acquisition source (CT, MRI, etc). This technique is essential for imaging equipment that does not use a standard format. This equipment (video card, computer, and modem) represents a small additional cost for capturing a transmitting these "small matrix" images.*

There are substantial additional costs to provide equipment that can acquire, store, and display "large matrix" electronic images (computed radiographs [CR] or digitized plain films). Large matrix images require expensive acquisition equipment (laser digitizer) and much more expensive workstations using more advanced computers with greater memory and disk storage. The largest additional incremental cost is for high resolution monitors. These acquisition systems may cost from \$45,000 to \$65,000 and high-resolution dual monitor workstations from \$40,000 to \$50,000.

There are also communication costs for transmitting images between facilities, either on telephone lines (long distance charges) or on dedicated, high-speed lines (lease charges plus additional, dedicated interface equipment). Image compression techniques will substantially reduce the costs associated with electronic image transmission by compressing large image data files to a much smaller size, selectively discarding some of the data while preserving critical diagnostic information. Validation of these algorithms is underway in many electronic imaging laboratories.¹⁹ The telecommunications infrastructure in rural areas is limited. Communication costs could be substantially reduced by sharing a statewide, fiber optic telecommunication infrastructure with government and industry.

FUTURE TRENDS IN TELERADIOLOGY

Teleradiology will probably develop in three phases. The first phase is mature, and consists of "on-call" transmission of images to physician's homes. The images flow is from a PC to a PC, over a phone line/modem, and the information system is a combination of phone, voice mail, or fax to the emergency room or ward. A preliminary impression is rendered, and the official interpretation is performed using a full resolution video display and/or film.

The second phase of teleradiology development is already occurring in larger practices. Radiologists will be in the hospital, 24 hours a day, providing continuous services and coverage. Multisite practices will centralize official interpretation of images in a hospital PACS system, receiving images from outlying facilities which feed into the

*The ACR Teleradiology Standard defines resolution and image display specifications for both "small matrix" (CT, MR, US, nuclear images) and "large matrix" (digitized radiographs, CR) digital images.

hospital PACS. These systems will include an elementary information system to assist with work management and reporting.

In the third phase, individual facilities will be linked to other provider systems as a single enterprise. Large, linked PACS systems will be as-

sembled over a WAN to provide images to radiologists and clinicians throughout a multisite enterprise. The essential missing piece required to assemble the seamless imaging system of the future is a standards-based, fully integrated enterprise medical information system.

REFERENCES

1. Goldberg MA, et al: New high-resolution teleradiology system: Prospective study of diagnostic accuracy in 685 transmitted clinical cases. *Radiology* 186:429-434, 1993
2. Wilson AJ, et al: Evaluation of the injured cervical spine: Comparison of conventional and storage phosphor radiography with a hybrid cassette. *Radiology* 193:419-422, 1994
3. Franken EA Jr, et al: Evaluation of a digital workstation for interpreting neonatal examinations. A receiver operating characteristic study. *Invest Radiol* 27:732-737, 1992
4. Jonsson A, et al: Film-screen vs. digital radiography in rheumatoid arthritis of the hand. An ROC analysis. *Acta Radiol* 35:311-318, 1994
5. Jonsson A, et al: Computed vs. film-screen magnification radiography of fingers in hyperparathyroidism. An ROC analysis. *Acta Radiol* 36:290-294, 1995
6. Kido S, et al: Interpretation of subtle interstitial lung abnormalities: Conventional versus film-digitized radiography. *Radiology* 192:171-176, 1994
7. Kido S, et al: Clinical evaluation of pulmonary nodules with single-exposure dual-energy subtraction chest radiography with an iterative noise-reduction algorithm. *Radiology* 194:407-412, 1995
8. Langen HJ, et al: Comparative evaluation of digital radiography versus conventional radiography of fractured skulls. *Invest Radiol* 28:686-689, 1993
9. Scott WW Jr, et al: Interpretation of emergency department radiographs by radiologists and emergency medicine physicians: Teleradiology workstation versus radiograph readings. *Radiology* 195:223-229, 1995
10. Thaete FL, et al: Digital radiography and conventional imaging of the chest: A comparison of observer performance. *AJR* 162:575-581, 1994
11. Wilson AJ, Hodge JC: Digitized radiographs in skeletal trauma: A performance comparison between a digital workstation and the original film images. *Radiology* 196:565-568, 1995
12. Kimme-Smith C, et al: Effects of reduced exposure on computed radiography: Comparison of nodule detection accuracy with conventional and asymmetric screen-film radiographs of a chest phantom. *AJR* 165:269-273, 1995
13. Mosser H, et al: Conventional film-screen versus computed storage phosphor radiography. Simulated military lung disease in an anthropomorphic phantom. *Invest Radiol* 30:186-191, 1995
14. Don S, et al: Volume detection threshold: Quantitative comparison of computed radiography and screen-film radiography in detection of pneumothoraces in an animal model that simulates the neonate. *Radiology* 194:727-730, 1995
15. Scott WW Jr, et al: Subtle orthopedic fractures: Teleradiology workstation versus film interpretation. *Radiology* 187:811-815, 1993
16. Halpern EJ, et al: Evaluation of teleradiology for interpretation of intravenous urograms. *J Digit Imaging* 5:101-106, 1992
17. Dawood RM, et al: Clinical diagnosis from digital displays: Results and conclusions from the St Mary's evaluation project. *Br J Radiol* 67:1-10, 1994
18. Yoshino MT, et al: Diagnostic performance of teleradiology in cervical spine fracture detection. *Invest Radiol* 27:55-59, 1992
19. Goldberg MA, et al: Application of wavelet compression to digitized radiographs. *AJR Am J Roentgenol* 163:463-468, 1994