MR Teleradiology Network Serving Remote Imaging Centers

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The operational experience of a commercial teleradiology practice utilizing a wide-area ISDN network linking six imaging centers located in two states will be reviewed. Open magnet designs were chosen to complement existing high-field units available in each community. Image data was first acquired then transmitted without compression at 128 Kbytes/s to a central reading site located in McLean, Virginia for interpretation by a team of radiologists. Average transmission time was 6-8 minutes. System design allows optimal utilization of radiologists expertise in imaging interpretation while reserving the on-site patient management responsibilities such as gadolinium contrast injections and sedation to a non-radiologist physician and/or nurse practitioner. Over 15,000 teleradiology readings have been rendered via this network by January 1998.

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TELERADIOLOGY has well accepted applications for on-call consultations, often from the radiologists home, as well as obtaining secondary opinions in difficult cases. This can overcome geographical barriers to make services available regardless of location. Teleradiology permits a consultant's expertise to be available to many sites almost simultaneously. This also has the potential of economy of scale, which is important in the present era of managed care and declining financial reimbursement.

The aim of this venture is to develop a commercial teleradiology service to serve MR imaging centers widely separated in distance over two states, and linked by a wide-area network. Secondary goals are to enhance image interpretation by triaging examinations to MR subspecialists and increasing speed and availability of service to rural practitioners.

METHODS

An initial pilot study was begun in December of 1994 with the establishment of routine and emergency MR services in Hagerstown and Salisbury, Maryland. The central reading station was located in McLean, Virginia (Fig 1). A third site in Frederick, Maryland was added in July of 1997; and a fourth out of state

site in Toledo, Ohio was brought on line in September of 1997. A fifth center will begin service in Marietta, Ohio in March of 1998 and a sixth site in Findlay, Ohio will start shortly thereafter in May of 1998. Mid-field open MRI systems were chosen to complement existing high-field units already installed in the communities. The first two centers are equipped with Hitachi (Model 7000) 0.3T permanent magnet design; units three and five with 0.3T Hitachi (Airis); and unit four with a Toshiba (OPART) MR system. Hours of operation are variable, depending on patient volume, and typically run from 0700 to 1900 hours. Each center is staffed by two teams consisting of technologists and a receptionist whose shifts overlap at the busy mid-day period. Emergency and after-hour services are available but are rarely needed.

Patients are offered examinations within 24 hours of initial screening, if desired. Patient histories and imaging protocols are reviewed by telephone by the radiologist and technologist, and the referring physician if necessary (before the patient is scanned). The radiologists are licensed in the States of Ohio and Maryland as well as the adjacent states of Pennsylvania, Delaware and Virginia.

The remote imaging centers, the central reading station, and three radiologists' homes are linked together by a wide area ISDN network allowing transfer of image data at a rate of 128 kilobytes per second. This allows image interpretation and transfer of image data from any of these sites within the network. At the completion of an MR examination, scan data is transmitted from the scanner via a merge box (Merge Technologies) to an image server. The merge box converts the imaging files into a DICOM 3.0 format compatible with the image management work station. These local computers have disk capacity of approximately 4.5 GByte (enough to hold data from approximately 250-300 cases). Data is then transmitted via a router (Ascend Communications Incorporated) over an ISDN line without compression. The McLean Virginia reading center consists of three physician PC-based workstations (RadWorks Applicare Medical Imaging, Netherlands), each equipped with two 21" monitors and separate disk capacity of 9 Gbytes interlinked between each workstation, allowing instantaneous sharing of data within the central reading site. These 2K high resolution monitors are greater than the original MR data, and allow remote windowing and leveling of images. Furthermore, the system design allows visualization of the local data servers and transfer of image data sets from any point within the network. For example, this allows the radiologists on call to pull data acquired at a remote location to his home reading station without need of assistance from an on-site technologist.

Examinations are triaged for interpretation among a team of fellowship trained radiologists consisting of two senior neuroradiologist and one senior musculoskeletal-sports medicine specialist. A hard film copy of each examination is made for the patient and/or the referring physicians. No films are stored on-site. Digital storage is based on a magneto-optical disk. A radiologist's preliminary report is typically faxed to the physicians office within 2 hours after the completion of the study. These preliminary reports are generated using the same PC-based workstations equipped with standard word processing software which allows transfer of individual images to the facsimile

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Fig 1. Location of MR Centers in Maryland and Ohio.

along with a brief typed impressions. Finally, centrally transcribed reports are usually complete within 24 hours and transmitted, electronically to the MR sites. From the sites, reports are either faxed to the physician's office or forwarded electronically to the referring physician's computer. A copy of the report is also posted to the referring physician.

Patient satisfaction is monitored by follow-up questionnaires. Physician satisfaction is monitored by office visits from marketing representatives from the imaging centers and less frequently by the Medical Director.

RESULTS

The referral base of each site varied between 500 to 1000 physicians. Initial patient volumes beginning in the first year of operation were typically between 1500 and 2000 exams and typically rose approximately 20% per year in subsequent years. The case mix for typical MR operations, consists of approximately 25% musculoskeletal examinations and 5% body examinations, with the remaining 70% being neuroradiology examinations, of which 40% were of the lumbar spine.

The MR systems used at all sites proved robust with only one scheduled outage (due to external power failure during a winter snow storm, which caused the cancellation of one day's scanning at

one site). Routine maintenance was performed by an in-house technician to reduce overhead. During the first few months of service in the Winter of 1995, there were several telecommunication problems associated with ISDN lines, merge box and routers which occasionally required films to be delivered by courier service. These problems have become less frequent as ISDN providers gained experience. One router and one merge box has been replaced during the course of the study.

Beginning in the third year of operation, the initial teleradiology equipment (Cemax-Icon Clinical View, Fremont, California) was replaced by the previously described RadWorks PC-based system. Both systems proved durable with no interruption of service. Several hurdles had to be overcome in operating a MR center without an on-site radiologist. Sedation of both children and adults with oral medication is managed by a nurse familiar with radiology procedures. This was required on the average twice a month at each site for two hours on each occurrence. Intravenous sedation was monitored on-site by a radiologist. This was required on average once per month at each site. During a site

visit, the radiologist was able to report images from the local diagnostic work station from examinations carried out either locally or remotely from other sites within the network.

A decision was made early on not to require the presence of a radiologist during routine gadolinium injections, but to rely on non-radiology physicians cover from elsewhere within the medical complex. No adverse reactions to gadolinium were experienced during the study. Patients with suspected ocular foreign matter were screened routinely by obtaining orbital radiographs for interpretation by local radiology groups before the MR appointment. Relevant reports from previous examinations were requested from the physician's office after scheduling patients. In most cases, this proved satisfactory for correlation with the current examination. In a minority of cases, correlative films were sent by courier to the central reading station.

The cost of transmission for an individual patient examination via ISDN was approximately \$1.25. This was based on a fixed monthly line rental of \$45.00 per month and usage charge of .17 cents per minute.

Transmission time between sites for a typical MR examination was consistently 6-8 minutes, close to the expected ISDN transmission time based on a 4.9 megabyte file size ($256 \times 256 \times 12 \text{ bits} \times 50 \text{ images}$) and a 67% protocol efficiency. This transmission time was relatively insensitive to distance. To demonstrate this, in September of 1995, long distance transmission of MR data sets was performed between the central reading station in McLean and an international conference in Germany (Intelevent 1995). The transmission times were approximately 8 minutes per exam. Responses to questionnaires were generally favorable, citing prompt scheduling and performance of examinations as well as a caring attitude of the experienced technologist. Above average to excellent ratings were given by more than 90% of the respondents. Physician satisfaction was generally excellent and both solicited and unsolicited letters cited turn-around in terms of patient scheduling, imaging and final transcribed reports. Accuracy of interpretations is often given as a reason for change in referral patterns. The lack of direct radiology contact with a hospital was rarely indicated as a disincentive to refer patients.

Patient scan volumes at both centers gradually increased throughout the study and by the end of the study's second year of operation the two

original sites have exceeded those of the local hospitals high-field MR units.

DISCUSSION

Problems with healthcare in rural regions are substantial in the United States. Specialists are generally less available in rural areas. The shortage typically includes subspecialty radiologists. Teleradiology offers greater access to health services reducing travel time for physicians and patients which has an overall positive effect on patient healthcare. In tertiary academic centers, cases are routinely divided before interpretation by organ or modality. Similarly, a teleradiology practice allows triaging of difficult cases to subspecialist. This is not necessarily the case in many private community radiology practices. For example, such practices may divide their relatively small MR caseload between many radiologists with varying degrees of MR training and ability. In a teleradiology practice, a single expert reader can interpret up to 10,000 cases annually. This enhances the teleradiologist's competency especially when interpreting less frequently requested musculoskeletal examinations such as hand/wrist and foot/ankle. Not unlike other designs of picture archiving communication systems, this model avoids problems with misplaced and lost films. Digital imaging report retrieval is possible 24 hours a day. This is not necessarily true for films especially when the patient is given the responsibility for delivery to a rural physician office.

The conclusions of a previously reported economic analysis¹ suggests that teleradiology service can be designed as a more cost effective model than a more traditional courier service. More significant, however, is the speed of delivery of the final image interpretation. With a few hours of training, a radiologist operating from an electronic work station is as fast or faster than reading from conventional films.^{2,3} This is especially true in settings where the radiologist must hang and eventually remove the films (as well as relevant prior examinations for comparison).

The American College of Radiology standards for image acquisition and digital display technologies for teleradiology were met by the system used in the present study.⁴ Demonstration of the diagnostic equivalency of reading from the digital work stations vs. hard copy films has been well documented in the literature.⁵⁻⁷ The advantage of direct digital capture is that it affords the radiologist

access to full 12 bit data sets without degradation. This allows the radiologist to adjust window and level settings, an inherent advantage over conventional film. The requirements of low resolution modality such as Computerized Tomography, MR, ultrasound and nuclear medicine is easily exceeded by the 2K monitors used in this practice.

The transmission times of uncompressed MR files are approximately 6-8 minutes over ISDN operating at 128 kilobytes per second. This compares with anticipated times of 30 minutes per case with a standard telephone line and modem operating at 28.8 kilobytes per second. Data compression would make conventional phone lines a practical option at current caseload. However, plan expansion (in terms of more sites and additional modalities such as computerized tomography) would eventually result in serious bottleneck, and therefore, the system was designed at the outset to use higher bandwidth transmission lines.

Operating costs were similar to those predicted in the economic model reported previously.¹ Further economies of scale can be realized, since a single radiologist should be able to interpret examinations from 3-4 scanning units. The cost of the additional telecommunications equipment and the ISDN charges are easily offset by the savings realized in a film-less environment and the cost in sending films to an off-site radiologist.

It is noteworthy to point out a few of the minor problems encountered which may be more frequent in a rural practice. First, several referring practitioners do not possess fax machines. One option utilized was to purchase this standard piece of office equipment for them so that our speed of service could be realized. Second, the potential of utilizing the Internet to transfer images directly to referring physicians computers appeared attractive, but we found many practitioners did not possess office computers for this purpose. Of those that did, they demonstrated an indifference to this service. In a trial study involving a few larger referrals, the physicians failed to utilize their computers for this purpose. A common reason cited was the busy practitioner did not have time to learn the necessary computing skills nor enough time in his/her work

schedule to review imaging studies via computer, preferring the more familiar film medium.

There are several upgrades in our service presently under evaluation. Average time required to generate a final report using a conventional transcription service is limited to about 24 hours in most private practices. Utilizing voice-recognition software available to PC's has been shown to reduce report turn-around to under 6 hours in some centers.⁸ The occasional need for film couriering to the central office could be eliminated via film digitizers to aid comparison with prior studies. Finally, improvement of image quality has recently been upgraded by the implementation of a DICOM 3.0 compatible, commercially available image enhancement system (Image Enhancement System, Hayward, California) interfaced with our image servers. Preliminary experience with these noise reduction algorithms are that they both decrease the acquisition time of scanning protocols as well as raise the overall signal-to-noise ratio comparable to "unenhanced" high-field systems. Finally, in the near future, our ISDN network will be replaced with dedicated wide-area network connection using frame relay.

CONCLUSIONS

A teleradiology practice, as reported here, allows for subspecialty triaging of both routine and difficult cases, a model usually restricted to large academic centers. Technical advances now permit transmission of large patient data sets over long distances for rapid routine interpretations as well as secondary consultations with other specialists, if needed. The interstate MR teleradiology service described links a central reading center located in McLean, Virginia to six geographically separated sites (via an ISDN network). Approximately 15,000 interpretations have been completed in this fashion in the first three years of operation. To our knowledge, this private commercial teleradiology practice is unique. While the use of teleradiology after hours and on-call coverage is commonplace,⁹⁻¹¹ we are not aware of any other practice which owns and operates commercially both the imaging centers and the teleradiology network.

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