Filmless picture archiving and communication in diagnostic radiology

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Abstract

A survey is presented of recent changes in digital image acquisition for diagnostic radiology. New digital image archiving, communication and management strategies are proposed and discussed. A possible scenario for the development of digital Picture Archiving and Communication Systems ("digital PACS") in diagnostic radiology is presented, starting with a research/teaching environment and ending with a large scale clinical environment. This scenario is presented as a sequence of five strategies with increasing levels of digital archiving and communication and requires five key concepts. We briefly discuss each key concept and present possible implementations, given today's technology. A preliminary evaluation of proposed image archiving strategies is made. The paper concludes that the development of a PACS that provides partial on-line digital storage is feasible today.

Introduction

A Picture Archiving and Communication (PAC) system is part of every diagnostic radiology and nuclear medicine department. However, most of today's PACS consist of centralized analog film file rooms. The current film file room manages both the analog generated radiographic images and the video raster film recordings used for imaging of digital diagnostic images. Several diagnostic image management strategies relying upon film file room type PACS are in use today[1,2].

The purpose of this paper is to identify and discuss a "digital PACS" development scenario in diagnostic radiology suitable for the next few years. The scenario will assume today's technology and the need for digital storage to facilitate medical research and perhaps to improve the clinical usage of digitally acquired diagnostic images. We divide our scenario into a sequence of five "digital PAC" strategies with increasing amounts of digital archiving and communication. Different implementations of this scenario for the development of "digital PACS" are technically feasible today, and we attempt to give several examples of implementation for each strategy. However, the ultimate "digital PACS" will require the development of key concepts or components which will be discussed in this paper.

The paper will focus on "digital PACS"; i.e., PAC systems providing full digital storage of images. On-line digital storage precludes the use of "analog film-based storage". However, off-line digital storage can be realized by digitally encoding images on a strip of film. So, even though "digital" does not necessarily imply "filmless", in this paper we will sometimes loosely refer to "digital PACS" as "filmless PACS". "Analog PACS", i.e., PAC systems providing analog storage of images (such as film file rooms[1,2], microfilm systems[3] or analog video tapes/discs), will not be addressed.

Today, departments of diagnostic radiology are using a greater percentage[4] of imaging systems that generate digital images. These systems include computed tomography scanners for head and body imaging, ultrasound scanners equipped with digital display memories, nuclear medicine gamma cameras and digital radiography imaging systems. Eventually other imaging sytems, such as nuclear magnetic resonance scanners, will be added to the list. In the future these digital systems may also include systems that digitally acquire chest X-ray images (which are now generated in analog form) and other new imaging modalities.

There are many reasons to examine "digital PACS" and the consequent new image management strategies for diagnostic radiology. First, as stated above, more and more imaging systems produce images in digital form. Second, technological breakthroughs in digital storage[5] and broadband communication[6] make small-scale filmless digital PACS feasible today. Third, according to a study of a 600 bed hospital in Kansas City7, the cost of storing digital radiographic images in analog form on film and the management of this archive, accounts for 75% of the total cost of digital image management. This fact indicates that a shift in archiving and management strategy away from analog video film recordings might induce a reduction in image archiving and management costs.

Current procedures for PAC

We will review and compare the ways in which digitally acquired diagnostic images are archived in both a clinical setting and a research/teaching setting. We emphasize that today only a fraction (approximately 30%) of all diagnostic radiographic images is acquired in digital form. This fraction will increase[11] to 50% during the next few years. Digitization of chest X-ray size images is not considered in this section. We will limit our comparison to X-ray CT, ultrasound and nuclear medicine imaging. Modalities such as digital fluorography, digital radiography and nuclear magnetic resonance imaging are not in sufficiently wide spread use to be included.

In a clinical environment, digitally acquired images are usually recorded on film using multiformat video raster gray scale film recorders and then added to the film jacket, which is stored in a centralized film file room. In some hospitals, all digital CT images produced during one day are stored on a magnetic disc or tape which is purged at the end of each day. However, for most X-ray CT images the radiologist has a preferred CT window setting for each anatomical site, and the windowed digital image is recorded as an analog image on film. Nuclear medicine images require less storage than CT or ultrasound images, usually need to be processed (for dynamic studies), are stored on film or polaroid and are not routinely archived in digital form for long periods of time. Most ultrasound scanners have digital scan converters and a digital image memory, but only provide a video display output. There is usually no convenient interface to the digital image memory, and ultrasound images are stored on multiformat film, polaroid or analog video tape/disc.

The shortcomings of today's use of digital images in a clinical environment can be summarized as follows. Digitally acquired images are recorded in analog form with a video raster gray scale film recorder. Most of the advantages of "digital" access to the information are therefore lost. However, today's use of an analog storage medium is a necessity. Diagnostic radiology departments have rooms equipped with "light-boxes" to read film. Many physicians have small light-boxes in their offices. It would be very inconvenient to the average clinician if all diagnostic images could not be viewed in the same way. The majority of diagnostic images still consists of analog generated large X-ray film, and therefore dictates the choice of the viewing station.

The factors dictating the choice of an analog viewing station in a clinical environment will become less important during the next few years for several reasons. First, more and more quantitative information, such as ultrasound tissue characterization and X-ray dual energy analysis, is being used by clinicians for research and specialized exams. This type of information will soon be used in everyday clinical practice and will require the use of digital viewing stations as a complement to the conventional (analog) light-box. Second, the fact that all pictures are now added to the patient film jacket, and stored in the film file room, increases the file room size needed for analog storage on film (more so than digital storage would require) and adds to the inconveniences of manual film retrieval. Third, today's utilization of available computation power, especially in nuclear medicine, is not optimal. If all computing were made available on a shared and distributed basis, the equipment would be used in a more efficient way.

In a teaching/research environment, digitally acquired images are kept in digital form for as long as they are needed or for as long as it is physically possible to keep them given the size limitations of the archive. Both X-ray CT and nuclear medicine images are usually archived on magnetic tape or disc. Some ultrasound equipment manufacturers now provide interfaces to the scanner's image memory and thus allow direct retrieval of the digital image information. In the case of X-ray CT and ultrasound images one is limited in the total amount of images that can be stored (see Refs 4 and 7 for data on memory size needed for different images).

The shortcomings of today's use of digital images in a teaching/research environment can be summarized as follows. The only flexible, practical and widely used digital storage medium is magnetic tape. Clinical researchers want to be able to store any image in digital form. Because the volume of magnetic tapes required for such purposes increases very rapidly, and the image retrieval is slow and sequential, this type of database can not be used efficiently. To compound the problem, each imaging modality usually produces a different image format. These restrictions sometimes force the researcher to use a viewing station connected to the instrument being used for clinical exams to view images, and put the researcher and clinician in direct competition for access to clinical instruments.

Without affecting the operation of today's clinical diagnostic department, research and/or teaching could drastically be improved and facilitated. In order to do so, a digital PAC sub-system needs to be developed within existing radiology departments[8] that provides one or a combination of the following capabilities. The first capability is an image communication network, which is a digital link between each imaging device and computing, archiving, and viewing stations. An image communication network allows any digital image to be archived at any time in a temporary archive. The second capability is a digital image database that is sufficiently large to accomodate the volume of images needed for research/teaching during a number of days or weeks. The third capability is a system that allows shared use of computer power and viewing stations. If all three of these capabilities were available, researchers and teachers could have easy access to any diagnostic image with interesting pathological, clinical or technical features. The clinical radiologist would not be affected, because each digital image would still be recorded on film as usual. The radiologist's help would be needed, however, in selecting the clinically interesting images.

Proposed image archiving and management strategies

As stated above, digital PAC sub-systems might be helpful for teaching/research and are not too difficult to develop. On the other hand, the development for clinical use of a full scale digital PACS to replace today's centralized analog film file room will take many years of experimenting and research. A global digital and filmless PACS will have to be easy to use, be effective, provide fast access, be user friendly and cost effective to the average clinical diagnostic radiologist. We therefore do not foresee any major quantum jumps in the development and utilization of filmless PAC systems. Rather, we expect a slow, steady evolution in time. Cost may become a less important factor in the decision to switch to digital PACS, as routine clinical demand for quantitative parameters (such as tissue characterization or dual energy radiography) may become major determinants in the decision to change. Technological breakthroughs will soon remove the last roadblocks to a totally digital PACS.

We will now describe a possible "digital PACS" development scenario, consisting of a sequence of five different strategies for image archiving and management, starting with a status quo strategy and ending with a full-scale digital PACS strategy. We foresee a "digital PACS" development scenario where equipment manufacturers and the medical community join efforts to proceed from one strategy level to the next. Each strategy in our list brings us further from the analog film file room and closer to a filmless digital PACS. Each strategy is one step in a PACS development scenario for the coming years. For each strategy we give different ways to implement the general features of the strategy. While giving this step-by-step prediction of the evolution of PAC system development, we identify five key components or concepts needed for filmless PACS. These concepts are discussed in more detail in the next section.

Strategy #1

This strategy is the starting point in our PACS development scenario and consists of leaving things the way they are today: a status quo. Archiving is done in centralized film file rooms. The image management strategy is a function of both the non-picture patient record filing system and the film file room organization. As mentioned earlier, some of the diagnostic images are stored digitally on tape or disc for special research or teaching purposes. Long term archiving is sometimes achieved with movable shelf microfilm systems[3].

Strategy #2

This strategy is the second step in the "digital PACS" development scenario and basically corresponds to what was suggested at the end of the previous section: provide researchers/teachers with easy access to the digital information, but in a way that is transparent to the clinician. This strategy does not affect the day to day operation of clinical diagnostic imaging procedures and does not interfere with the clinician's work. Figure 1 shows an implementation of this strategy for digitally generated imaging data.

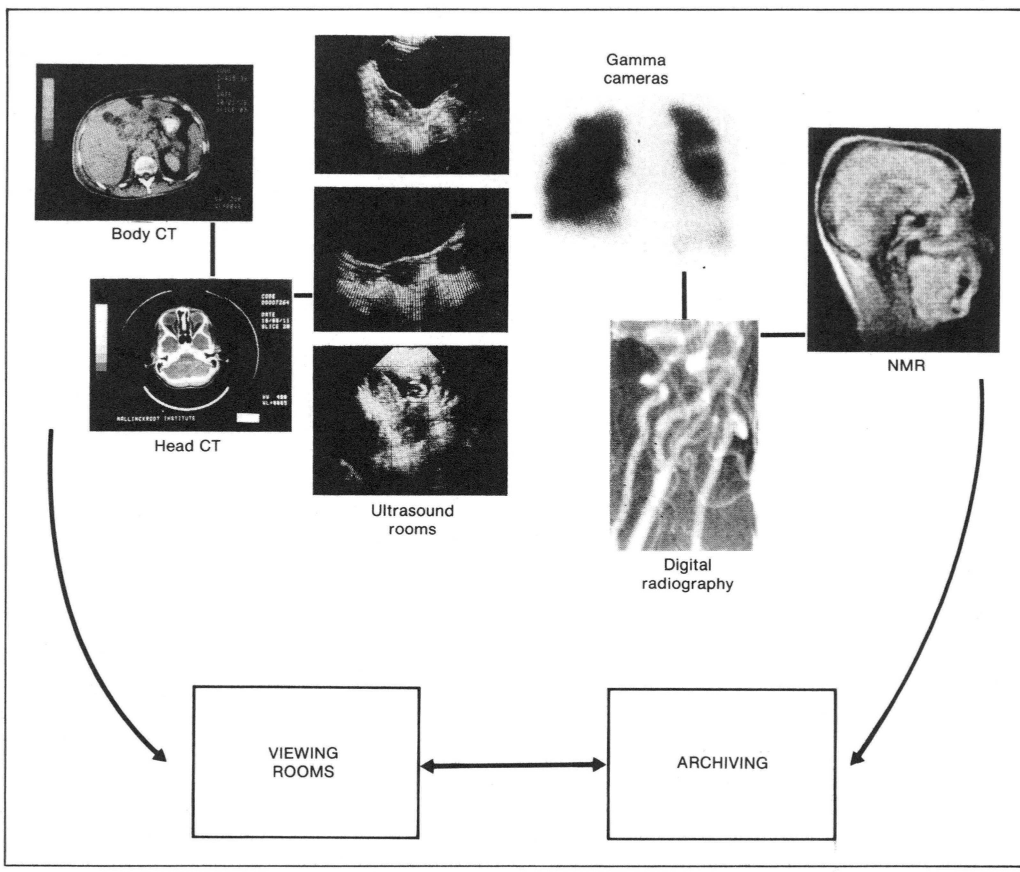

Figure 1. Archiving and recall strategies for digitally generated imaging data--from ultrasound, CT, nuclear medicine, and eventually digital radiography and nuclear magnetic resonance equipment--will probably require combinations of magnetic discs, optical discs, magnetic tapes and possibly laser film recorders and solid state storage devices. Not only will archiving be an important part of the storage system, but so will a means to rapidly retrieve all of a patient's images several times during his or her stay in the hospital. (Figure provided courtesy of Diagnostic Imaging[15], Nov 1981 issue)

Strategy #2 calls for a digital PAC sub-system, consisting of a combination of any of the following four parts:

- A digital optical disc based archive, allowing on-line storage of several weeks worth of research related images (see discussion of concept #1 in the next section).
- A fast access magnetic disc based archive, allowing storage of data acquired in real-time.
- An image communication network (see discussion of concept #2 in the next section) connecting nuclear medicine cameras, ultrasound scanners, X-ray CT scanners, a central computer and a small archive (see Ref. 8).
- High resolution displays for parallel and sequential viewing of images (see discussion of concept #4 in the next section).

Strategy #3

This strategy is the third step in the "digital PACS" development scenario and it involves slightly more than strategy #2, in that it affects the way the technologist uses the imaging equipment and his/her interaction with the radiologist. Three examples of capabilities that would allow a partial implementation of strategy #3 are:

- Local on-line archives for each imaging modality (i.e., distributed database), with each archive large enough to store several days' worth of images. This database would take away the need to store images on film during the patient's examination (see discussion of concept #1 in the next section).
- Shared distributed computing and display resources in nuclear medicine.
- A filmless PAC sub-system for ultrasound. Such a PAC sub-system would interconnect all ultrasound examination rooms and scanners with one main viewing room, and also provide on-line archive capability for up to 3 days' worth of images. The system would totally change the operation of ultrasound procedures: there would be no need to first make hard copies of the ultrasound images before the patient can be released. The radiologist can quickly check all the images, prior to releasing the patient. No film is wasted.

Strategy #4

This strategy is the fourth step in the "digital PACS" development scenario, and it will have a stronger effect on the operation of the clinical part of the radiology department than strategy #3. This strategy allows the clinician to use conventional light-boxes to view large size X-ray images, but high-resolution video displays (see discussion of concept #4 in the next section) will be available to view digital images stored in digital form. Hard copy on film will only be provided for long-term archiving or outside consulting by another physician.

Strategy #4 calls for on-line digital storage capability of all images produced in digital form over a period of time. Two implementation approaches can be taken: a centralized archive or a distributed archive (see concept #1).

A first approach is the centralized archive, where all images are stored on a day to day and patient by patient basis. The time period over which the database is maintained can be chosen in many different ways:

- a fixed time period; e.g., 3 days, 20 days or 2 months;
- the duration of the patient's stay in the hospital;
- the time needed for the course of therapy;
- the time needed to complete a clinical research project.

A second approach is a distributed archive where a physical archive partition is provided for each imaging modality; i.e., each imaging modality will have its own archive. Because different imaging modalities produce different picture formats, a different amount of data will be archived for each imaging modality; for example: 3 days' worth of images for ultrasound, 40 days' worth for nuclear medicine, and 5 days' worth for X-ray CT.

Another useful capability to be implemented at the level of strategy #4 is the sharing of image display, recall and processing resources.

Strategy #5

This strategy represents the final step in the "digital PACS" development scenario and brings us toward a fully digital, partially on-line PACS in diagnostic radiology and nuclear medicine. The strategy will, when implemented, drastically change the clinical operation of a radiology department. We distinguish, rather arbitrarily, three different ways to implement the strategy:

- Digital encoding of all diagnostic images on a patient-by-patient basis on an individual image "credit card" for long-term archiving (the image "credit card" is concept #3 to be discussed in the next section);
- Digital acquisition (also for X-ray; see discussion of concept #5 in the next section) and short-term (e.g., several days or weeks) on-line storage of all diagnostic images;
- Digital acquisition (also for X-ray) and long-term (e.g., several months or years) on-line storage of all diagnostic images; i.e., a digital radiology department.

It should be noted that none of the above five strategies addresses the problem of Management Information Systems (MIS) with computerized patient record keeping and patient file management. A standard way of encoding the final radiology consulting report has not been agreed upon yet. Therefore, we do not wish, in this paper, to dilute the main issue (i.e., a scenario for the development of "digital PACS") by incorporating uncontrollable and unpredictable human factors into our discussion (see Refs 1,2 for such discussions). We want to make it very clear that a PACS, providing the physician with picture access and a patient name and date, is a viable concept with virtually none of the human interface problems and disagreements about a standard encoding method for computerized patient record keeping. It is beyond the scope of this paper to consider the combination of both MIS and PACS.

New concepts needed for PACS

While presenting our PACS development scenario and discussing the above five strategies, we identified five key concepts needed to proceed from a film-based "analog PACS" to a fully filmless, partially on-line "digital PACS". We will now detail these concepts, state their purpose and give possible implementations.

1. The electronic picture archive

The purpose of the electronic picture archive is to provide on-line short-term or long-term digital image archiving, with fast retrieval of images. Short-term refers to several days or a few weeks. Long-term refers to many weeks or several months. Fast retrieval means: fast enough to allow user friendly parallel viewing of up to 30 images.

An electronic picture archive could be implemented by using any one or a combination of:

- digital optical disc recorders;
- laser film encoders;
- magnetic tape/disc drives;
- solid state memories.

Such an electronic picture archive would allow both hard and soft copy production. Quantitative image information extraction becomes possible. Also, savings in film otherwise wasted on poor pictures and repeat radiographs are to be expected.

2. A picture communication network

The purpose of a picture communication network is to provide fast (broadband) digital communication between imaging devices, different on-line archives, and viewing stations.

The picture communication network could be implemented using coax or fiber optic technology. The network configuration could be a local area network based on a single or double ring or a bus structure. The information exchange could be accomplished using a standard network communication protocol. Ethernet has been mentioned as a possible choice[9].

The picture communication network could be used for transfer of three types of information: control information (short "packets" for status reporting); electronic mail (consultation reports, patient data, management data); and image records.

3. An image "credit card"

The purpose of the image "credit card" is to provide off-line long-term digital storage of images, on a a patient-by-patient basis. It might eventually replace the patient film jackets in use today. The term "image credit card" is somewhat misleading because its implementation does not necessarily require a medium similar to a conventional (financial) credit card. However, it is called a "credit card" to convey the message that its implementation will be significantly less bulky than today's film jacket.

The image "credit card" could be implemented by using an optical medium with digital encoding, such as a mini optical disc or a strip of film. Another approach would be to use a solid state memory. VLSI technology will certainly open up new possiblities in the area of large memories. In order to be practical, the "credit card" should be either updatable or cheap to replace and duplicate. Wide spread use of such a digital archive will require the introduction of standard viewing stations in many locations within the hospital.

The very real requirement for long-term storage (i.e., over a period of several years) should never be overlooked. The two most important reasons for keeping diagnostic image records over a long period of time are, first, for legal reasons and this requires storage for a period of several years. But even more important, the second reason is that many diagnoses depend on a comparison of an image acquired now with an image acquired last year, the year before, etc. A fairly significant number of diagnoses would be missed if previous images were not available for comparison, since small changes in pathology can only be recognized by comparison with previous images. Therefore, until an image "credit card" medium becomes available, radiologists will have to rely on bulky and costly media (film or conventional digital storage) for long-term archiving.

4. A high resolution display

The purpose of the high resolution display is the parallel (i.e., simultaneous) viewing of up to 30 pictures and also the sequential viewing of dynamic studies.

For its implementation, a special purpose image computer architecture seems most appropiate. Several manufacturers[12,13] provide partial solutions to this problem.

5. A system for real-time digital acquisition of large X-ray images

The primary purpose of such a digitizer would be to complete the last step in making diagnostic radiology a fully digital operation. It will allow wide spread use of digital radiography techniques.

Several digitization methods for large X-ray film are presently being tested[9,10]. Knowledge gained in developing cheap and fast film digitizers could later lead to cheap systems that acquire large X-ray images directly in digital form.

Evaluation of archiving strategies

The evaluation of archiving strategies requires criteria by which to predict the need for different PACS and PAC sub-systems in clinical diagnostic radiology. One can readily list three classes of criteria:

1. Technical factors, such as:
   - the daily volume of digital image data;
   - the speed required for image communication;
   - access protocols;
   - access speeds.

2. Cost-benefit factors, such as:
   - the archiving cost for each strategy;
   - the operating costs of different system configurations.

3. User interface factors, such as:
   - human acceptance of filmless operation.

We will limit the criteria used in our preliminary evaluation to technical and cost-benefit factors. Unfortunately, few studies[7] are available that attempt to estimate the cost of conventional analog film file room based archiving. More studies are available[7,9] that give estimates of the daily volume of data produced and the data rates required for communication.

We will use the results of a detailed study[7] at the University of Kansas Medical Center in 1981. The Medical Center is not necessarily representative of other hospitals or medical centers, but is a good (and the only available) start for any future discussions on and evaluation of PACS. The University of Kansas Medical Center is a 614 bed teaching hospital where most imaging modalities commercially available today are in clinical use. The detailed list of the instrumentation used and the daily flow of patients for each imaging modality are given in Ref. 7 and will not be repeated here. We will only restate two of the conclusions of the study:

(1) Use of imaging modalities such as X-ray CT, ultrasound, nuclear medicine and (projected use of) digital radiography will generate between 254 and 502 Megabytes of digital data daily. This number does not include analog generated radiographic film.

(2) Seventy-five percent (75%) of the cost of archiving and managing these image data is due to the use of video raster multi-format film recording.

It is also worthwhile to look at data available from European medical centers[10] and the New York University Medical Center[9]. These studies not only consider imaging modalities that produce digital images, but include digitization stations for analog generated radiographs. Maguire[9] envisions a 10-year transition period during which all old film is digitized each time it is recalled, and new film is immediately digitized. This transition period (toward an era where all images are acquired in digital form) will put heavy demands on a broadband communications system. Maguire estimates that about 5,500 Megabytes of image data would have to be stored daily during that transition period.

The conclusions of the above studies are that we need to store a lot of digital image data, and that we need a "very broadband" communication network. When one surveys today's available storage media, nothing comes close to being able to provide more than several days' worth of on-line digital image storage capacity. Even the non-erasable digital optical disc recorder only allows the recording of up to 1000 MBytes on each side of a disc[5]. A typical 2,400 foot magnetic tape reel, at a 1,600 Byte/inch recording rate, only stores about 42 MByte of data. Thus for short-term archiving more clever on-line archiving strategies will have to be developed to match both the clinical needs for immediate recall of part of the diagnostic images and the availability of storage hardware that is not overly complex or costly. For long-term archiving an image "credit card" type medium will have to be developed.

The cost estimates[7,9] for image archiving and management available so far are only a portion of total cost. Difficult to include are cost factors such as: hidden personnel cost, cost of infrequently used modalities (real-time archiving, etc.), and the hidden cost of software development and maintenance. The number of beds, hospital size, and whether or not all imaging modalities are available are factors that heavily influence cost estimates.

Cost may be less important[14] than patient care delivery and access to new technology. If digital PACS drastically improves short-term access to diagnostic images, it will most certainly replace analog film recordings for short-term archiving.

Conclusions: the future of filmless PACS

The future of digital PAC subsystems looks very promising. After the first introduction of PAC subsystems, the usage of film will, initially, not decrease significantly, but the access to diagnostic information will improve. Even after full-scale "digital PACS" will become an integral part of diagnostic radiology departments, a moderate amount of hardcopy on film will still be needed because of its convenience and portability.

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References

1. Arenson, R.L., Morton, D., London, J., Comprehensive Radiology Management System without PACS, Proceedings of the 1st International Conference and Workshop on Picture Archiving and Communication Systems (PACS) for Medical Applications (Abbreviated: Proceedings of the 1982 PACS Conference), Edited by André J. Duerinckx, SPIE Vol 318-61, January 18-21, 1982, Newport Beach, CA.

2. Quintin, J., Simborg, D., The University of California at San Francisco Automated Radiology Department without PACS, Proceedings of 1982 PACS Conference, SPIE Vol 318-62, January 18-21, 1982, Newport Beach, CA.

3. Medical Records Round up: Part II, Radiology/ Nuclear Medicine Magazine, Vol 111, No 5, pp 63-67, October 1981.

4. Robinson, R.G., The Use of medical Images in Today's Hospital, Proceedings of the 1982 PACS Conference, SPIE Vol 318-01, January 18-21, 1982, Newport Beach, CA.

5. Nadan, J., Blom, G., Chandra, S., Kenney, G., McFarlane, R., Recent Advances in Digital Optical Recording, Proceedings of the 1982 PACS Conference, SPIE Vol 318-07, January 18-21, 1982, Newport Beach, CA.

6. Kreutzer, H.W., Hermes, T., Fiber Optic Broadband Communication Systems- Design and Realizations, Proceedings of the 1982 PACS Conference, SPIE Vol 318-16, January 18-21, 1982, Newport Beach, CA.

7. Dwyer III, S.J., Templeton, A.W., The Cost of Managing Digital Radiographic Images, Proceedings of the 1982 PACS Conference, SPIE Vol 318-02, January 18-21, 1982, Newport Beach, CA.

8. Dwyer III, S.J., Templeton, A.W., Anderson, W.H., Tarlton, M.A., A Distributed Diagnostic Image Information System, Proceedings of the 1982 PACS Conference, SPIE Vol 318-33, January 18-21, 1982, Newport Beach, CA.

9. Maguire, Jr., G.Q., Zeleznik, M.P., Horii, S.C., Schimpf, J.H., Noz, M.E., Image Processing Requirements in Hospitals and an Integrated Systems Approach, Proceedings of the 1982 PACS Conference, SPIE Vol 318-35, January 18-21, 1982, Newport Beach, CA.

10. D. Meyer-Ebrecht (private communication)

11. G.J. Arink (private communication); the 50% fraction refers to the share of images produced with X-ray equipment.

12. La Jeunesse, R.P., A New System Architecture for Medical Image Processing, Proceedings of the 1982 PACS Conference, SPIE Vol 318-42, January 18-21, 1982, Newport Beach, CA.

13. Clouthier, R., Digital Storage and Fast Communication Links for Medical Image Analysis, Proceedings of the 1982 PACS Conference, SPIE Vol 318-43, January 18-21, 1982, Newport Beach, CA.

14. Vanden Brink, J.A., Present Practive and Perceived Needs - the Medical Imaging Market, Proceedings of the 1982 PACS Conference, SPIE Vol 318-74, January 18-21, 1982, Newport Beach, CA.

15. Duerinckx, A.J., Dwyer III, S.J., Pisa, E.J., Digital Image Archiving and Management, Diagnostic Imaging, November 1981 (pp 62-63), a Miller-Freeman Publication.