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The Cost of Managing Digital Diagnostic Images

A study of the cost of recording and archiving digitally formatted diagnostic images is presented for an academic radiology department serving a 614-bed university hospital and a large outpatient population. The radiological examinations include computed tomography, nuclear medicine, ultrasound, and digital radiography. The archiving management strategies studied include the combined use of computer magnetic tapes, computer disc storage, and multiformat video film recordings. The estimated cost per patient for the archiving of digital diagnostic images is presented.

Index terms: Images, storage and retrieval • Radiographs, storage and retrieval • Radiology and radiologists, departmental management • Radiography, digital

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During the past eight years, radiologists have added digital image information to their diagnostic repertoire. Digitally formatted images are obtained from computed tomography (CT) scanners for both head and body, nuclear medicine gamma cameras, ultrasound scanners equipped with digital display systems, digital radiography or fluorography imaging systems, and other new imaging systems such as the whole body nuclear magnetic resonance (NMR) scanners. The utilization of digital diagnostic images is characterized by five steps: production of images from a single diagnostic modality, physician diagnosis, integration of image information from more than one diagnostic modality, storage, and retrieval.

The storage and retrieval of digital images has already become a major information management problem. The purpose of this paper is: (1) to document the amount of digital diagnostic data that requires management; (2) to estimate the cost of managing digital diagnostic data; and (3) to identify technologies that will influence the storage and retrieval of digital diagnostic images in the near future.

Estimation of Diagnostic Digital Image Generation

Diagnostic examinations that generate digital images are identified in Table 1, and the algorithms used for calculating the entries in this and subsequent tables are provided in the footnotes. Table 1 presents an estimate of the amount of digital data to be managed during a single working day from an academic radiology department serving a 614-bed hospital group (somewhere between 254.81 megabytes [254.81×10^6 bytes] and 502.77 megabytes [502.77×10^6 bytes] of image data per day.

For the CT scanner, the radiologist usually reviews each reconstructed image on a display station as it is being generated. The multiformat video film recordings of the CT scans are then used in preparing the consultation report and are subsequently placed in the patient's film jacket. Due to the limited disc storage space on the CT scanner system, the scans are archived from the disc onto magnetic tape for long-term storage. A heavily utilized CT scanner requires the archival of all CT examinations onto magnetic tape at the close of each working day.

State of the art dynamic and static nuclear medicine studies are acquired and stored initially on a magnetic disc or magnetic tape. Multiformat video film recorders are used to record the scans for clinical interpretation. Since the digital array size and the gray scale range of nuclear medicine images are smaller than for CT, it is possible to keep these images on the disc for several days before archiving on magnetic tape or floppy discs. As Winchester sealed discs (storage capacity of 33 megabytes) are interfaced to nuclear medicine systems, the interval of time between required archivals will increase; hence, the archiving process for nuclear medicine studies is similar to that

[1] From the Department of Diagnostic Radiology, the University of Kansas College of Health Sciences and Hospital, Kansas City, KS. Received 12 August 1981; revision requested 30 November and received 22 December; accepted 26 March 1982.

for CT studies, with the exception that images are archived to tape from disc less frequently.

Ultrasound examinations are imaged using film in multiformat video film recorders. Microcomputers may provide for the transfer of the image information contained in the ultrasound digital display system, through an interface, to a digital storage device. However, as seen in TABLE 1, the amount of ultrasound data per scan is such that several discs would be completely filled each working day. The increasing use of real time ultrasound scanners will require an effective means of acquiring and archiving several selected frames of digital data from data that is being generated at over 2 megabytes per second.

Current digital fluoroscopy units digitize the video signal from the output of the television intensifier chain, producing a digital array that is 256 × 256 × 10 bits or 512 × 512 × 10 bits; in future, the digital array may be expanded to 1,024 × 1,024 × 10 bits. While these images are generated at the usual television rate of one frame per 1/60 second, the rate at which the digital processed images are presented to the viewer varies from one to ten images per second.

Estimation of the Cost of Archiving Diagnostic Digital Images

Obviously, archiving the amount of diagnostic digital image data identified in TABLE 1 is a significant problem. Two strategies for managing these data use either digital computer peripheral devices such as discs or magnetic tapes, or multiformat video film recorders. In TABLE 2, the estimated costs are given for generating and archiving magnetic tapes. For both nuclear medicine and ultrasound examinations these costs include additional required computer equipment as detailed in the footnotes of TABLE 2. Also included are estimates of the amount of storage space required for storing magnetic tapes, and an estimated cost per patient to temporarily store the image data on easily accessible discs for a 5-day period. Increasing interest in the processing of digital diagnostic images to quantify diagnostic parameters will require such temporary on-line storage. After five days, the cost of archiving to magnetic tape (TABLE 2, notes 1-4) will be incurred. An estimate of the cost for retrieving a patient's magnetic tape is also provided.

TABLE 1
Estimate Of Digital Data To Be Archived Per Day From An Academic Radiology Department Servicing a 614 Bed Hospital Population

	Body CT Examinations	Head CT Examinations	Nuclear Medicine Examinations: Static Image Acquisition	Nuclear Medicine Examinations: Dynamic Image Acquisition	Ultrasound Examinations	Estimated Digital Radiography Examinations
Number of Patients Per Day	10 to 13[1]	12 to 15	20 to 30	8 to 12	15 to 20	10 to 15
Number of Images Per Patient	20 to 40[1]	16 to 20	4 to 8	15	30 to 42	12 to 16
Total Number of Bytes of Required Storage Per Day	36.1×10^6 Bytes[2] to 93.9×10^6 Bytes[2]	34.67×10^6 Bytes[2] to 54.17×10^6 Bytes[2]	2.64×10^6 Bytes[3] to 7.89×10^6 Bytes[3]	0.499×10^6 Bytes[4] to 0.749×10^6 Bytes[4]	117.98×10^6 Bytes[5] to 220.22×10^6 Bytes[5]	62.92×10^6 Bytes[6] to 125.84×10^6 Bytes[6]
Number of Magnetic Tapes Required Per Day	1.72 or 2 reels[7] to 4.47 or 5 reels[7]	1.65 or 2 reels[7] to 2.58 or 3 reels[7]	0.126 or 1 reel[7] to 0.376 or 1 reel[7]	0.0238 or 1 reel[7] to 0.0357 or 1 reel[7]	5.62 or 6 reels[7] to 10.49 or 11 reels[7]	3.00 or 3 reels[7] to 5.99 or 6 reels[7]
Number of Units for Patient Load	1	1	5 Nuclear Medicine Cameras		3 Ultrasound Scanners	1

Total Estimated Daily Digital Image Data Storage Required:
254.81×10^6 Bytes to 502.77×10^6 Bytes

(1) CT examinations are classified by the anatomic sites of chest, abdomen, pelvis and extremity; thus, one patient may have more than one CT examination.
(2) The diameter of the CT reconstruction circle is 320 pixels, requiring approximately 90,000 pixels for one image. Each pixel requires 2 bytes of storage. In addition, 1,024 bytes of storage are required for patient identification information and 512 bytes for each scan. Total bytes of storage = (180,512 × N slices + 1,204) × no. of patients.
(3) For nuclear medicine static image acquisition, it is assumed that the digital array size is 128 × 128, or 16,384 pixel values. Each pixel requires 2 bytes of storage for adequate representation. In addition, 1,024 bytes are required for patient identification. Total bytes of storage = (32,768 × N images + 1,024) × no. of patients.
(4) For nuclear medicine dynamic image acquisition, it is assumed that the digital array size is 64 × 64, or 4,096 pixels. Each pixel requires 1 byte of storage. In addition, 1,024 bytes of storage are required for patient identification. Total bytes of storage = (4,096 × N images + 1,024) × no. of patients.
(5) For an ultrasound digital scan converter, it is assumed that the digital array size is 512 × 512, or 262,144 pixels. Each pixel requires 1 byte of storage. An additional 1,024 bytes of storage are required for patient identification. Total bytes of storage = (262,144 × N images + 1,024) × no. of patients.
(6) For an estimate of the data storage of a digital radiography system, assume that the digital array size is 512 × 512 or 262,144 pixels. Each pixel requires 2 bytes of storage. An additional 1,024 bytes of storage are required for patient identification. Total bytes of storage = (524,288 × N images + 1,024) × no. of patients.
(7) Assume that 1 reel (2,400 ft. long, recorded at 800 bytes/in.) can store a maximum total of 21×10^6 bytes (8,192 bytes/record + ½ in. record gap). Note that the next highest integer is chosen; thus, 4.12 reels will be recorded as 5 reels of required magnetic tape.

TABLE 3 on p. 316 gives estimated costs for the multiformat video film recording of digital image data. These estimates include the 5-year prorated cost of the current film multiformat video recorders and the 5-year prorated cost of a dedicated film processor. Also included are estimated labor costs to expose and develop the multiformat films.

Using TABLES 1-3, the cost of archiving digital data for a particular department's spectrum of imaging systems can be estimated. For example, the yearly cost of archiving body CT digital data for 10 patients per day is calculated by: {(($3.27 per patient for magnetic tape generation) + ($0.809 per patient for magnetic tape retrieval) + ($14.55 per patient for multiformat video film recordings) + ($18.47 per patient for a 2-year period of archiving multiformat video film recordings)) + ($3.79 per patient for 5-day on-line disc storage)} × ((10 patients per day) × (250 working days per year)) + ($1.75 for magnetic tape storage space) = $102,223 cost per year. In a similar manner, the reader may evaluate cost estimates for combinations of strategies.

The Demand for Archived Diagnostic Digital Data

The demands for archived diagnostic digital images occur at three successive times. First, the patient's examinations are conducted and the consultation report developed. This is a period of

TABLE 2
Estimated Cost Of Daily Archiving Of Diagnostic Digital Image Data On Computer Peripheral Devices

	Body CT	Head CT	Nuclear Medicine: Static Image Acquisition	Nuclear Medicine: Dynamic Image Acquisition	Ultrasound	Estimated Digital Radiography
Cost of Magnetic Tape Generation Per Patient	$3.27 to $5.95[1]	$2.72 to $3.17[1]	$1.79 to $1.19[2]	$4.47 to $2.98[2]	$8.22 to $9.89[3]	$4.75 to $6.14[4]
Cost of Magnetic Tape Retrieval Per Patient	$0.809[5]	$0.809[5]	$0.809[5]	$0.809[5]	$0.809[5]	$0.809[5]
Required Storage Space for Magnetic Tapes Per Patient[6]	$1.97 \times 10^{-3}(m)^3$ to $3.78 \times 10^{-3}(m)^3$	$1.639 \times 10^{-3}(m)^3$ to $1.968 \times 10^{-3}(m)^3$	$0.491 \times 10^{-3}(m)^3$ to $0.328 \times 10^{-3}(m)^3$	$1.229 \times 10^{-3}(m)^3$ to $0.8195 \times 10^{-3}(m)^3$	$3.93 \times 10^{-3}(m)^3$ to $5.41 \times 10^{-3}(m)^3$	$2.95 \times 10^{-3}(m)^3$ to $3.93 \times 10^{-3}(m)^3$
Cost of Required Storage Space for Magnetic Tapes Per Patient[7]	$0.0007 to $0.0014	$0.0006 to $0.0007	$0.0002 to $0.0001	$0.0005 to $0.0003	$0.0015 to $0.0020	$0.0011 to $0.0015
5 Day On-Line Cost of Disc Storage Per Patient[8]	$3.79 to $7.36	$3.04 to $3.73	$0.219 to $0.321	$0.281 to $0.208	$ 7.98 to $11.10	$6.47 to $8.51

(1) Assume that the CT digital display images are to be transferred from the CT system disc to digital magnetic tapes *via* the CT system tape drive (800 bpi drive). Assume no costs are incurred for use of the disc and tape drive since they are part of the CT system. The cost is calculated on the basis of: (($14/reel X N reels) + (15 min./reel to transfer CT scans from disc to magnetic tape X N reels @ $3.50/hr. labor costs) + (30 min. to transfer N reels to storage area @ $3.50/hr. labor costs) + (20 min./day to properly record notebook log of tape nos. and run nos. @ $3.50/hr. labor costs)) ÷ (no. of patients/day) = cost/patient.

(2) Each nuclear medicine camera has a disc drive or tape drive which acquires the digital image data. To archive these data properly on magnetic tape requires an additional tape drive unit ($15,000) connected to an available computer system. The cost of this tape drive is charged to the archival of the digital images and is prorated over a 5-yr. period. The cost is calculated on the basis of: {(($15,000 cost of tape drive ÷ 5-yr. proration) + (10% of tape drive cost for maintenance/year)) ÷ (250 working days) + ($14/reel X N reels) + (15 min./reel to load digital images on tape x no. of reels/day @ $3.50/hr. labor costs) + (30 min./day to transfer N reels to storage area @ $3.50/hr.) + (20 min./day to properly record notebook log of tape nos. and patient ID's @ $3.50/hr. labor costs)} ÷ (no. of patients/day) = cost/patient.

(3) Ultrasound digital scan converters provide for a digital interface connection by which digital image display data may be transferred to a computer peripheral device; however, peripheral computer equipment has to be added. Assume that two 33 megabyte Winchester disc drives ($5,000 for a 33 megabyte disc drive + $500 for an interface) and a tape drive ($15,000) are connected to the digital scan converter. These costs are prorated over 5 years. Cost calculated on the basis of: {(($10,000 for 2 disc drives + $1,000 for disc interfaces + $15,000 tape drive) ÷ (5-yr period) + (10% of equipment costs for maintenance/yr.)) ÷ (250 working days) + ($14/reel X number of reels) + (15 min./reel to load digital images on tape X number of reels) + (15 min./reel to load digital images on tape X no. of reels/day @ $3.50/hr. labor costs) + (30 min./day to transfer N reels to storage area @ $3.50/hr.) + (20 min./day to properly record notebook log of tape nos. and patient ID's @ $3.50/hr.)} ÷ (no. of patients/day) = cost/patient.

(4) Assume no costs are incurred for use of a disc and tape drive since they are likely to be integral parts of the digital radiography system. Cost is calculated on the same basis as that for CT (see above, note 1).

(5) Upon request for a patient's digital images, the record log of archived tapes is searched, and the particular tape (images may be stored on 2 or more tapes) is identified. The correct tape is acquired from the storage area and loaded back into the system from which it was generated (or into an independent viewing system), then the tape is returned to the storage area. Due to the extensive use of multiformat video film recordings, the request for archived tapes is estimated at a recall rate of approximately 10% of the no. of patients/day. Further, it is estimated that approximately 25% of these recall requests will involve a duplicate magnetic tape of the patient's image data. This incurred cost of magnetic tape retrieval and tape duplication should be prorated as a charge to all patients. Cost is calculated on the basis of: {(10% of the no. of patients/day) X ((30 min. to identify correct tape storage no. from record log and acquire tape from storage area @ $3.50 labor cost/hr.) + (15 min. to load tape back into system @ $3.50/hr.) + (30 min. to return tape to storage area @ $3.50/hr.)) + (25% of the 10% no. of patient recalls/day will want duplicate magnetic tapes) X (($14/duplicate reel of tape) + (15 min. @ $3.50 labor cost/copy))} ÷ (no. patients/day) = cost/patient.

(6) Each 2,400-ft reel of magnetic tape is 3/4″ thick and has a diameter of approximately 12″. In an 8-ft. high room, 6 rows of tapes may be stored vertically. If magnetic tape storage shelves are used, then each shelf is approximately 30″ wide (holds 2 rows of tapes) and at least 30″ of aisle access space should be allowed. As an approximation, each tape requires 1″ width X 15″ height X 40″ length (allows for aisle access). Thus, a room that is 18′ X 18′ X 8′ high will hold approximately 7,250 reels of magnetic tapes. If 29 tapes are generated each working day (250 working days/yr.), then this room will be filled in 1 yr. Storage space is calculated on the basis of: (600 $(in.)^3$ X no. of reels/day 1.639 X $10^{-5}(m)^3/(in.)^3$) ÷ (no. of patients/day) = required storage space/patient.

(7) Assume that magnetic storage space costs $30/$ft.^2$/yr. and the volume required for each tape is 0.347 $ft.^3$. In order to store 7,250 tapes, a room with dimensions 18′ X 18′ X 8′ suffices. The total cost is $9,720/yr., or $1.34/tape/yr. By a simple conversion, the cost is $136.45/$m^3$/yr. Spreading this cost over 365 working days, we obtain a cost of $0.375/$m^3$/day. The daily cost of magnetic tape storage is given by: (($0.374/$m^3$/day) X (storage space/patient)) = cost/patient/day.

(8) Assume that all digital images are to be temporarily stored on disc for 5 working days. This disc storage is provided to enable rapid access to all digital radiographic images and then, after 5 days, data are loaded on magnetic tape (see notes 1–4). Cost is calculated on the basis of: {(amount of bytes to be stored in 5 days) ÷ (33 X 10^6 bytes/disc) X ($5,000 cost/disc + $500 interface) ÷ (5 yrs.) + (10% of equipment cost for maintenance/yr.) ÷ (250 days/yr.) + (30 min./day to transfer data to on-line disc storage $3.50/hr.)} ÷ (no. patients/day) = cost/patient.

great intradepartmental patient activity that places a high demand on accessing any and all images. Multiple examinations and geographically separated imaging systems combine to stress any system for archiving these diagnostic images. Multiformat video film recordings must be acquired and presented in the proper consultation room, together with the patient's film jacket. Computer disc storage of these digital diagnostic images could provide instantaneous access to this information.

Next, during the patient's stay in the hospital or another healthcare facility, there is a demand for access to the archived images for consultation, patient treatment planning, and teaching functions. Multiformat video film recordings of digital diagnostic images stored in the patient's film jacket help facilitate access to a large amount of image information. Storing of digital image data using computer peripheral devices would thus be helpful, especially if retrieval time needs to be minimized.

Finally, there follows the long period when diagnostic images are required by outpatient clinics, for the monitoring of long-term treatments, or for studies in disease progression or remission. These demands decrease significantly once the patient has left the hospital. Long-term archiving demands for diagnostic digital data are currently satisfied by multiformat video film recordings or magnetic tapes.

TABLE 2 provides the cost per patient for archiving digital diagnostic images using standard computer peripheral devices; the estimated demand utilization is shown in the footnotes. TABLE 3 provides the cost per patient for storing multiformat video film recordings. The cumulative cost per patient for the simultaneous archiving of multiformat video film recordings, magnetic tapes, and 5-day on-line disc storage systems can be determined using Tables 1–3. Using these data, it can be shown that: (*a*) the average cost per patient for archiving multiformat video film recordings is approximately 74% of the total; (*b*) the average cost per patient for storing magnetic tapes is approximately 14% of the total; and (*c*) the average cost per patient for archiving on a 5-day computer disc online system is approximately 12% of the total. By using higher density magnetic tape drives and an image data compression scheme of 2 to 1, the average cost per patient for archiving onto magnetic tapes can be reduced by 18%. We can expect the cost of archiving on digital storage devices to decrease. Multiformat video film recording costs could be reduced if the digital diagnostic image data were readily available for image display; hence, the greatest opportunity to reduce storage costs is to focus on the archiving of multiformat video film recordings.

Available Devices that Will Influence Archival Strategies

A cost-effective archival strategy for digital diagnostic images is dependent on the rapidly changing technology of digital storage systems, change that is brought about primarily by integrated circuit fabrication technology (1). Microelectronic technology is estimated to have exhausted only one-half of its ultimate potential (2).

Higher density tape drives and a data compression scheme (3–5) could significantly alter a storage strategy. For example, if all the current 800 bpi tape drives were to be replaced with a switchable 800 bpi/1,600 bpi tape drive ($15,000 cost), then only one-half the number of magnetic tapes would be required. In addition, a data compression algorithm could be applied to CT scan information that would compress the data to be stored by a factor of 2. An average 18% reduction in costs per patient for magnetic tape archiving could be realized; however, 3,200 bpi tape drives cannot be used because all previously recorded 800 bpi magnetic tapes would have to be rewritten at the higher density since 800 bpi/3,200 bpi tape drives are not interchangeable.

There are several reasons why video film recordings are so widely used. First, a few sheets of film and a view box provide for the simultaneous viewing of all the examination images and their chosen display parameters. Second, film recordings are easily stored in and retrieved from the patient film jacket. This provides an efficient method for diagnosis, consulting, and teaching. Third, films reduce the demand for computer display systems. Current computer display monitors present one or a few selected images at a time, requiring considerable time for the interactive viewing of a large number of display images.

Any technology or archival strategy that would reduce the number of required video film recordings could have a significant impact on the cost of archiving. One such technology is the use of a dry silver paper video recorder (6); another is the adoption of the laser film recorder for recording and retrieving digital diagnostic imaging data (7–9). Such a device would record digital data in encoded form on a film strip by exposing the film to a sequence of dot patterns. It is estimated that a density of 1 megabit per 2.5 cm^2 could be successfully archived on standard x-ray film and processed by conventional film processors. Such a device would enable the full dynamic range of the digital data as well as several analog images to be recorded on film. The original digital picture would be retrieved by the use of specialized read/write modules placed throughout the department.

Cost reduction in the long-term ar-

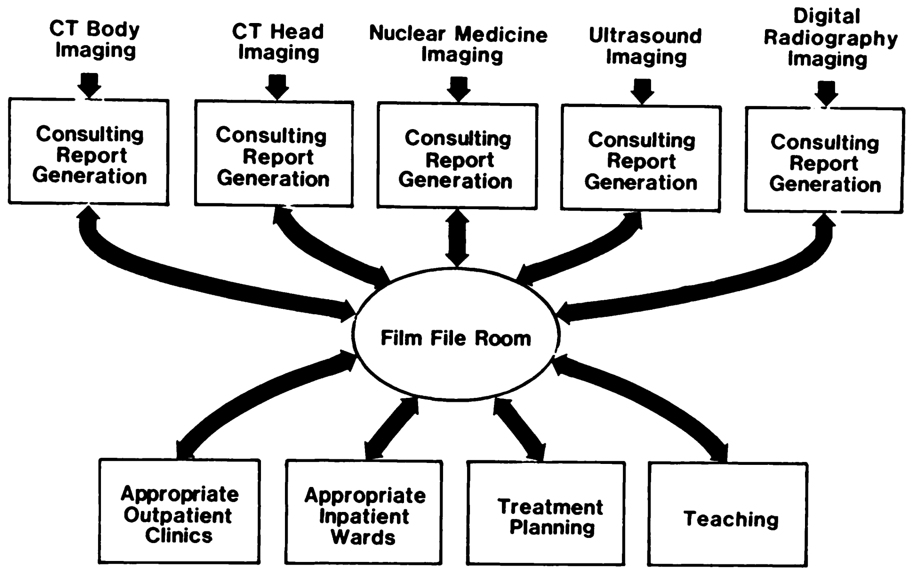
TABLE 3
Estimated Cost of Daily Multiformat Video Film Recording of Diagnostic Image Data

	Body CT	Head CT	Nuclear Medicine: Static	Nuclear Medicine: Dynamic	Ultrasound	Estimated Digital Radiography
Number of Film Sheets Recorded Per Patient	2 Sheets to 3 Sheets of 14 × 17 inch film[1]	2 Sheets of 14 × 17 inch film[1]	1 Sheet of 8 × 10 inch film[2]	1 Sheet of 8 × 10 inch film[3]	5 to 7 Sheets of 8 × 10 inch film[4]	2 Sheets of 14 × 17 inch film[5]
Cost of Video Film Recording Per Patient	$14.55 to $10.19[6]	$10.50 to $9.70[6]	20 Patients[7] MIN $2.28 MAX $3.07; 30 Patients[7] MIN $2.16 MAX $2.69	8 Patients[8] MIN $3.86 MAX $5.86; 12 Patients[8] MIN $3.50 MAX $4.82	$12.25 to $8.85[9]	$11.30 to $9.70[10]
Cost of Video Film Archiving Per Patient (2 Years)	$18.47[11]	$18.47[11]	$18.47[11]	$18.47[11]	$18.47[11]	$18.47[11]

(1) A General Electric Multiformat CT Film Recorder provides 12 recordings/14″ X 17″ sheet of film (II CT scan recordings + identification block). See TABLE 1 for no. of CT images/patient.
(2) Multiformat video film (MVF) recorders used in nuclear medicine provide up to 16 recordings/8″ X 10″ NMB sheet of film.
(3) The no. of MVF recordings for dynamic nuclear medicine examinations are usually limited to 1 sheet of 8″ X 10″ NMB sheet film (up to 15 recorded images).
(4) MVF recorders used in ultrasound recordings provide 6 recordings/8″ X 10″ sheet of film.
(5) It is estimated that a MVF recorder using 14″ X 17″ sheet film will be employed (11 image recordings + ID block).
(6) {(($30,000 cost of CT Multiformat Camera (CTMC) + $9,945 cost of Kodak M7B Film Processor (KFP)) ÷ (5-yr. proration) + (10% cost of CTMC and KFP for maintenance/yr.)) ÷ (250 working days/yr.) + (no. of sheets of film/day) X ($2.81/sheet of 14″ X 17″ NMB film) + (no. sheets of film/day) X ($0.15 chemicals cost/film) + (no. sheets of film/day) X (5 min./film cassette for loading and developing film @ $3.50 labor cost/hr.)} ÷ (no. patients/day) = cost/patient.
(7) Assume that there are 5 nuclear medicine cameras and that each has an MVF recorder costing $8,000. The equipment cost is to be prorated between the static and dynamic image acquisition. Cost is calculated as follows: {(($40,000 cost of 5 MVF recorders + $9,945 cost of KFP) ÷ (5 yrs. proration) + (10% cost of VFR and KFP for maintenance/yr.)) ÷ (250 working days/yr.) X ((no. of static images/day) ÷ (total number of acquired images/day)) + (no. of sheets of film/day) X ($0.99/sheet of 8″ X 10″ NMB film + $0.08 chemicals/film + 5 min./film cassette at $3.50/hr. for loading and developing film)} ÷ (no. of patient/day) = cost/patient. Note that there are 8 permutations for calculating the maximum and/or minimum costs. For this study, the maximum occurs for 20 static studies (8 images each) and 8 dynamic studies; the minimum occurs for 30 static studies (4 images each) and 12 dynamic studies.
(8) Cost calculated in the same manner as for static image acquisition, except that equipment and maintenance cost/yr. are multiplied by the following factor: (no. of dynamic images/day) ÷ (total no. of acquired images/day).
(9) Assume that each ultrasound multiformat film recorder costs $8,000 (6 images recorded/8″ X 10″ film) and that 3 are required (1 for each ultrasound scanner). Assume that one KFP is required. Costs are calculated as follows: {(($8,000 cost of MVF recorders X 3 cameras) + ($9,945 cost of KFP) ÷ (5 yrs proration) + (10% cost of video film recorders and film processor)} ÷ (250 working days/yr.) + (no. sheets of film/day) X ($0.99/sheet of 8″ X 10″ NMB film) + (no. sheets of film/day) X ($0.08 cost of chemicals/film processed) + (no. of sheets of film/day) X (5 min./film cassette for loading and developing film @ $3.50 labor cost/hr.)} ÷ (no. patients/day) = cost/patient.
(10) Costs are calculated by the same algorithm used for CT scan recordings (see 6).
(11) Assume that each patient's video films are archived in the Film Library in the patient's film jacket. Assume that the following average archival demands are made for the video film recordings: (*a*) an average of 10 requests during the first 10 days from a fast access suspension storage file with retrieval and storage times of 5 min. each; (*b*) an average of 4 requests during the following 2-month period from a permanent file with retrieval and storage times of 10 min. each. All subsequent requests will access this file; (*c*) an average of 2 requests during the following 10 mo.; and (*d*) an average of 2 requests during the following 12 mo. All labor charges are $4.25/hr. We also assume that 20% of all patients require an additional film jacket at $0.20 + $0.08 for file tape. Cost is calculated as follows: ((10 requests) X (10 min @ $4.25/hr) + (8 requests) X (20 min @ $4.25/hr.) + (20% probability that patient will require an additional film jacket @ $0.20 + $0.08 each for file tape)) = total archiving cost/patient for 2-yr archival.

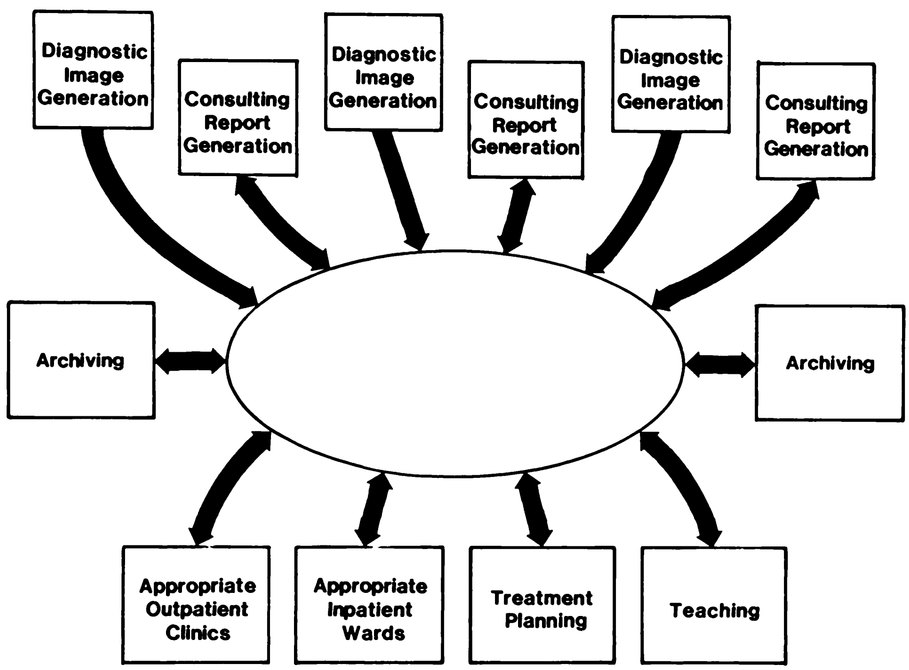
chiving of digital diagnostic data may be realized with the use of an optical disc (10). These "write-once" mass storage devices are now operational in laboratories. Small holes are burned by a laser onto a coated metal layer on the surface of the rotating disc. The holes are approximately 1 micron in diameter, giving a bit density of about 10,000 bits per cm and a track density of about 40,000 tracks per side with a disc 30 cm in diameter. A capacity of about 10 gigabytes is thus achieved. The laser also reads out the information that is stored. The projected storage cost range is about one microcent per bit or one-tenth the cost of magnetic tape. Contiguous element magnetic bubble devices offer yet another method of mass storage that could result in reduced costs (11). These laboratory devices now have a storage density of about 4 million bits per cm^2. Magnetic bubble storage will likely appear in the form of integrated circuit chips.

Figure 1



Centralized management strategy

Figure 2



Peripheral management strategy

Discussion

The current management of analog radiographic film images is based on a centralized strategy. With the advent of digital diagnostic imaging systems, multiformat video film recordings have been incorporated into this centralized concept as illustrated in Figure 1. This system provides for only sequential, one-at-a-time access to a patient's film jacket containing the multiformat, video recorded analog film images. To maintain the integrity of the original digital image data, a second centralized facility is required for archiving magnetic tapes (or discs). Storage of the digital data on magnetic tape is judged to be necessary in the event that questions arise regarding the parameters selected in making the analog video film recordings of the digital data. Centralized management for video multiformat film recordings and magnetic tapes is particularly stressful and inefficient. As imaging instrumentation shifts from standard radiographic film recording to digital acquisition systems, centralized management will shift towards those strategies that permit efficient sharing of digital diagnostic imaging data—a need exists to design and implement a peripheral digital image management scheme in place of the centralized concept.

A peripheral digital image management strategy that includes the three main functions of digital image acquisition, report generation, and archiving is illustrated in Figure 2. This scheme has many advantages. It should provide for much-improved management, sharing and control of digital image information. Using fiber optic cables, geographically separated areas of a radiology department would be interconnected, thereby improving patient care and overall department and hospital operations. Standardization of image formats would help the radiologist compare a patient's ultrasound, nuclear medicine or CT images before deciding to acquire additional examinations. Integration of multimodality diagnostic images would be achieved. An integrated image, multiuser system could reduce the time patients spend waiting for examinations and would reduce the physician's time in acquiring the most thorough patient consultation. Patient treatment planning functions would be optimized. Such a system should improve patient care by providing an efficient method for reviewing or archiving diagnostic data in designated outpatient or inpatient areas, and would permit improved modularity and reliability of individual diagnostic imaging systems.

On the basis of these cost studies, we believe that two pathways of action are possible for minimizing the cost of storing digital diagnostic imaging data. First, a department may elect to establish protocols for its requirements in managing digital diagnostic imaging data. The goal of such protocols would be to establish a mixture of multiformat video film recordings, magnetic tapes and on-line disc storage depending on the available imaging modalities, available expertise in their use, the patient population mix and the clinical resources to be expended. Second, a department can elect to begin implementing a peripheral digital image management strategy as illustrated by Figure 2. The prototype of such a system using fiber optic links in a local area network for integrating various digital diagnostic imaging systems is currently being developed at the University of Kansas.

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