# MARS - Missouri Automated Radiology System, Computer Graphics in an Automated Department*

Manson, D. J.; Lehr, James L.; Lodwick, G. S.
Department of Radiology, University of Missouri, Columbia

MARS is a radiologic information management system, automating information access and flow in three distinct areas: 1) management 2) medical and 3) radiographic image systems. The system's goal is to improve diagnostic patient care through fast information access and flow.

Management information storage, retrieval and display includes patient and fiscal control data. Patient flow is assisted by computer scheduling and expediting to optimize the use of radiographic facilities. Fiscal control includes storage and retrieval of patient billing, department accounts, and grant management information.

The results from two years of clinical use of the medical information automation program are presented along with a discussion of system modification made when transferring this system to a DEC PDP-15 department computer from the IBM 360-50 central processor.

The image information system includes production, storage, transmission, retrieval, display, information extraction and evaluation modules. Status of current research is reported for the radiographic evaluation module and for information extraction and automated diagnosis of rheumatic and congenital heart disease.

## Introduction

One begins increasingly to hear the phrase "out of control" in reference to rising health care costs. Whether or not the health care system is out of control, cost projections are beginning to approach 10% of the gross national product. A very small percent of health care costs represent the application of technology in medicine; computer automation techniques offer the promise to both increase the quality of health care and reduce costs. Our effort has been to apply these techniques to an entire department of Radiology and thus to test the cost effectiveness of automated health care in the clinical context. I am reporting today on modules of our system that involve the use of computer graphics.

I should like first to make a philosophical point. The concept of a total hospital information system is logically prior to that of any particular department. We begin by postulating that such a system will include a central file with selective access. By constructing a system that meets the needs of our department we will (1) have guaranteed the peripheral specification necessary to any system; 2) demonstrated a model for information processing applicable to other departments with similar information requirements; and 3) be ready to aid in the integration of intra-department information systems when they are ready.

This paper is concerned 1) with the medical information system being transferred to a small stand-alone computer; 2) with the system test of a 35 mm radiographic imaging system; 3) computer assisted diagnosis and 4) direct computer diagnosis from chest radiographs.

## Medical Information Processing

A USPHS survey** comparing the years 1964 and 1970 indicates that demand for radiological care is increasing much more rapidly than the supply of trained medical personnel. It is estimated that the average radiologist is experiencing a 20% increased demand on his time every year. The traditional radiology report is generated by a dictation and correction process relying on a typing pool and manual information processing. With increase of patient traffic there is often direct conflict between information flow and patient flow. Figure 1 depicts such a radiology department, over crowded and badly in need of automated information flow techniques.

In our department we have had an on-line clinical radiologic reporting system for over two years. Over 100,000 reports have been generated via this system. Figures 2, 3, and 4 show statistics acquired in clinical usage. It is seen that under the computer system over 75% of the reports reach the referring physician in about six hours whereas in the previous system the majority of reports were received the following day.

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** Preliminary estimates of the USPHS 1970 X-Ray Exposure Study. Charts for oral presentation at the session sponsored by the American College of Radiology at the Roentgen Ray Society Meeting, Boston, September 29, 1971

Figure 1. A RADIOLOGY DEPARTMENT IN NEED OF AUTOMATED TECHNIQUES. As health care facilities become over-crowded we may face a breakdown in the quality of health care if not of the entire system. Computer mediated information management can aid greatly in expediting information and patient flow in crowded facilities.

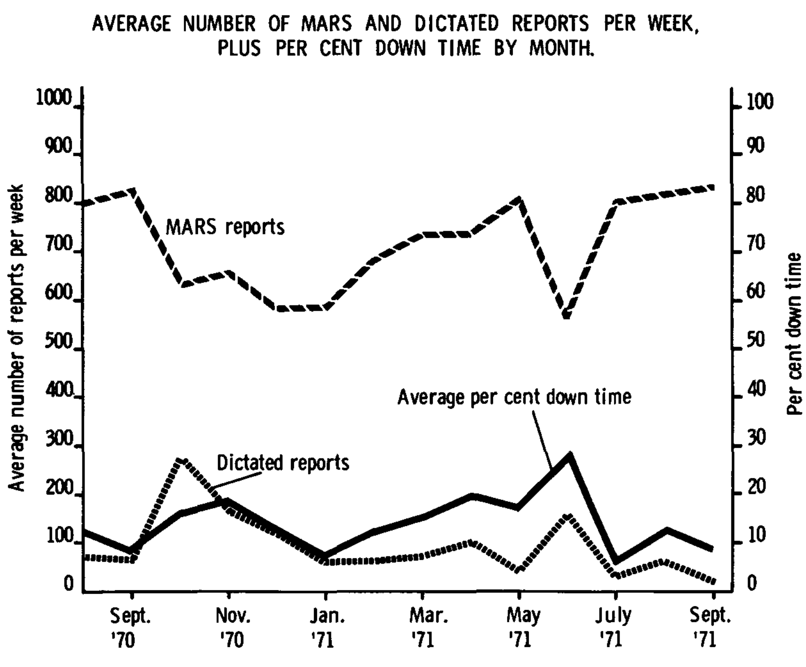


Figure 2. PHYSICIAN USE OF THE AUTOMATED REPORTING SYSTEM. Dictating system was used for backup. Central computer down time during clinical hours has averaged 10%. Use of dedicated computer for the MARS system will allow exporting system to other users and is expected to greatly improve reliability.

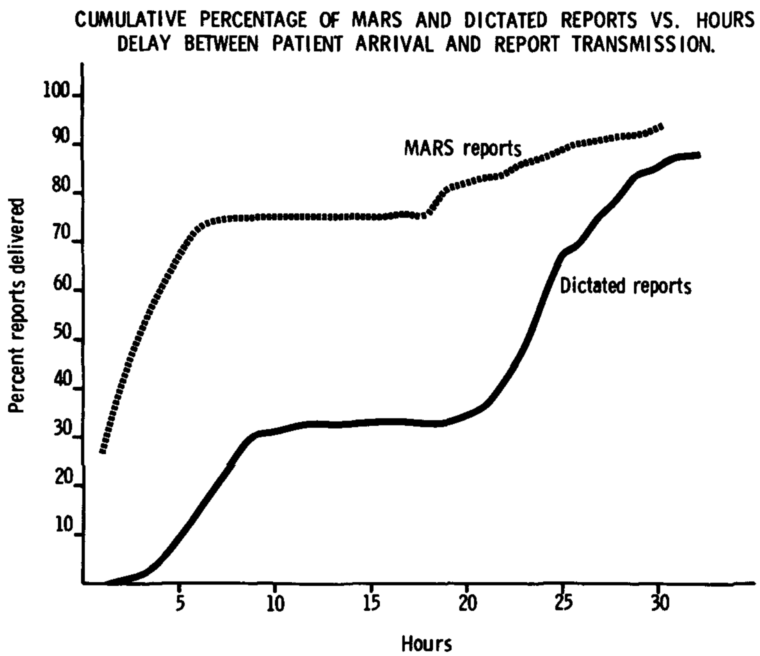


Figure 3. AUTOMATED REPORTING SYSTEM MAKES THE RADIOLOGIST'S REPORT MORE EFFECTIVE. Reports are typed at the wards and in film room for glueing to film jacket. Majority of reports are completed within six hours of patient's arrival in department using computer system.

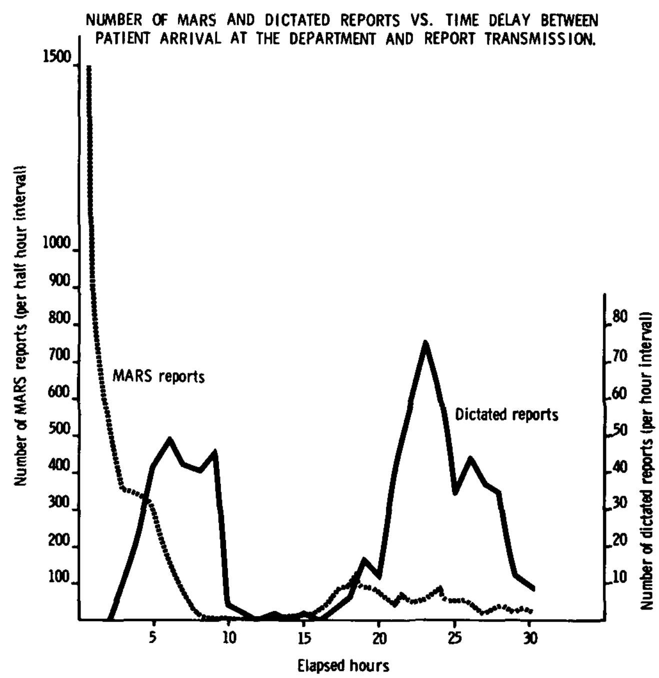


Figure 4. DISTRIBUTION OF REPORT COMPLETION TIMES. The automated system provides reports to the referring physician in time to be relevant for clinical decisions on patient disposition.

Critical concepts of the system include maximum use of clerical personnel; dispersion of information access and entry points (reception, diagnosis, files, ward); computer mediated transmission of reports; computer retrieval of reports and computer mediated assembly and checking of the report at interactive CRTs.

Principal objections to the system stem from physician reluctance to enter data via a key board and in some cases to the terse non-verbose nature of the report. It is our experience that these objections are minimal if the system saves the radiologist time, gets the report to the referring physician quicker and the computer operates consistently and reliably. Correlation of computer down time and use of dictated reports is indicated in Figure 2.

## Transfer to Department Stand-alone Computer

One of the advantages of automated systems is the availability of a continuous record of system performance. Our use of a central hospital computer has been plagued with an average 10% downtime. Problems have arisen with both hardware and systems software. Our current philosophy is based on the concept that the person responsible for health care must also be directly responsible for the means by which it is delivered. Further, the use of our software and graphics will now be exportable to other users. Independence of a large central CPU allows use of any of the MARS modules with a minimal hardware configuration keyed to the user's environment and needs. For these reasons we have implemented the transfer of the current MARS system to a PDP-15 department computer. The MARS system was transferred from FORTRAN coding to interpreter language (MUMPS) in less than six months (with considerable additions), with the aid of the MUMPS operating system. The new system is currently in the final debugging stage. Extensive use of statistics on frequency of usage from clinical operation was made in assembling the terminology tables of the new system.

The MUMPS system developed at Massachusetts General Hospital and documented and augmented by Digital Equipment Corporation is an interpretive language system with extensive string manipulation and file structure ability. We have observed approximately a 3:1 efficiency factor in programmer output compared to FORTRAN coding. The system allows protected time shared use of core; our current hardware allows up to 16 simultaneous users (28K-18 bit core, two 8 port, 2400 baud terminal scanners, 20 million words of disk storage).

We are combining many of the management information systems with the current clinical reporting system. Currently available with the report generation program are teaching file programs, coded report lookup programs, mnemonic "canned" reports with allowance for mnemonic use of individualized pet phrases, day sheet enquiry, patient scheduling, terminology table updating, and a referring physician patient summary. These options are displayed in menu form to the user who signs in with the MARS program, if he replies with a ? to the options interrogation. The system allows simultaneous developmental programming from remote CRTs; as modules are completed they are integrated under the MARS program. This is implemented easily with the call, overlay and protective features of MUMPS. Each terminal user has a slice of slightly over 1000 words of core. The resident system utilizes approximately 12K of core depending on the number of device handlers.

A typical example, Figure 5, will serve to indicate how the file structure and coding of the MARS system serve to offer the radiologist aid in quickly constructing a report. Combination of command and phrase codes allow most reports to be constructed and displayed from a single line entry. Maximal use is made of the physician's active memory and "menus" are displayed for passive memory selection only when he uses a four letter (or greater) mnemonic for which a terminology table search indicates there is more than one use of the term. In this case all phrases using the term are displayed for choice with the 1, 2, or 3 letter code designators which could have called the term or phrase to aid the active memory of the user for future use. Any report can be retrieved, in particular, by using the patient's name or ID number, or in general, by a Boolean combination of the key words of which the report is constructed. Hence one can

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EC/S UP LB L LNG/FCM=5.5 MSS "WITH SHAGGY BORDERS" /NCLC/ICA


EXAMINATION: CHEST, PA AND LATERAL
SITE: UPPER LOBE OF THE LEFT LUNG
FINDING: 5.5 CM. MASS WITH SHAGGY BORDERS
         NO EVIDENCE OF CALCIFICATION
IMPRESSION: CARCINOMA
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Figure 5. EXAMPLE OF CODING USED TO CONSTRUCT REPORT. Most reports are constructed and transmitted by typing a single line. The slash is used to force a new line in the output. If a physician does not remember a mnemonic code he types the first four letters (or more) of any word in the desired phrase. If the tables contain more than one such phrase all possibilities are displayed for the user choice of the correct phrase. The bottom five lines result from entry of the top line.

search for any Boolean combination of diagnosis, site or examinations and the search is specified using the mnemonic codes. Retrieval is fast because the code for the text is stored and not the text. Free text is allowed in constructing a report, but it is stripped when the report is permanently stored so that all such reports contain only vocabulary from the basic tables. These tables are extensive, but need to be stored only once. Reports are held in a work file in full format during the period in which they are actively used in the department and automatically converted to coded form after a fixed time interval from their inception. The MUMPS language allows fast recovery using only the pointers to the information. The MARS system is constructed so that neither the tables nor the reports need to be searched but the report and the terminology contained are assembled as the Boolean search is satisfied.

Patient scheduling presently utilizes only a simple computer mediated appointment book. Patient expediting, which involves computer checking of proper sequencing of examinations, the ability to block schedule for particular facilities and to integrate emergency needs is currently in the planning stage. Planning is based on an extensive Industrial Engineering analysis of our department and its relation to total hospital patient flow. Using the basic structure of the MARS system it will be a straightforward exercise to expand patient scheduling algorithms as soon as the integrated goals and terminal locations for patient flow are evident.

Fiscal management programs are not yet integrated under the MARS program but are being developed and tested as submodules. They rely more heavily on menu selection and the ability of the user to call for a menu with a question mark whenever his active memory fails. The basic charges accrued to each patient are of course kept with the stored report. The use of a common data base for all programs allows testing of developmental programs (which do not modify the data base) on-line with clinical operation.

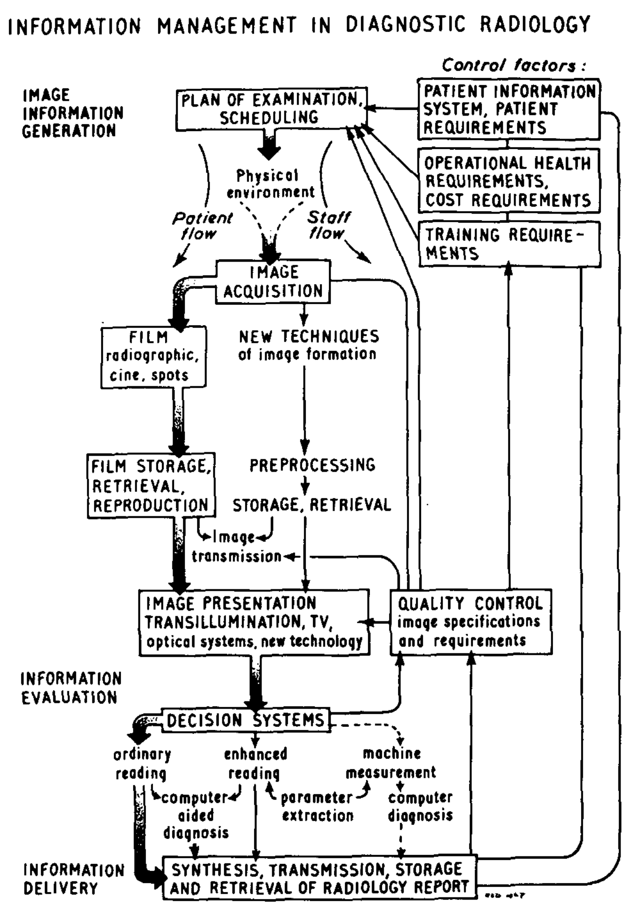


Figure 6. SCHEMATIC REPRESENTATION OF INFORMATION FLOW IN RADIOLOGY. Fiscal management information has been omitted for simplification. The MARS system goal is to automate information flow and retrieval for the entire department in modular form.

## Quantification of Diagnostic Content

A basic flow diagram for our department is indicated in Figure 6. Among the parallel paths indicated is automated diagnosis by computer. In order to effect machine diagnosis and especially to effect digital transmission of images it was necessary to create an evaluation tool so as to allow control of image quality (diagnostic content) without the continuous intervention and attention of our research physicians. To accomplish this a special test library of 5,000 cases was selected using the case retrieval capabilities of the MARS system. This library contains 20% of normals and representations of all radiographic abnormalities; also included are nuclear medicine scans and thermograms. Radiographs are graded for degree of difficulty of perception and degree of difficulty of diagnosis. Each film is examined by a team of ten physicians working independently. It would be impossible to accomplish such an effort in the busy clinical context if the information storage and retrieval were not automated. The terminology tables of MARS were used and the data base modified to allow this project a special subset of storage for compilation of separate statistics and records.

We are currently using the library to evaluate a 35 mm radiographic storage and imaging system by direct comparison of diagnosis with the original and with the projected 35 mm image. The entire library is therefore now available in 35 mm format. Performance and grading statistics for the 35 mm library will soon be available. Initial results are promising and if the statistics continue to indicate the effectiveness of the new system we will initiate clinical use for further evaluation.

It is certain that without the organization and communication offered by computer graphics such a study would be impossible. Can you imagine the difficulties of manually selecting such a library, much less getting physicians to manually code their diagnoses for research in a clinical context? Even an infinite clerical staff would have difficulty coping with the problem of deciphering physician handwriting.

Computer Assisted Diagnosis

Figure 7 is an expression of Bayes' theorem applied to probabilistic determination of diagnosis based on frequency of symptom and disease. While a physician certainly normally does not perform such a mathematical exercise, nevertheless his diagnosis often reflects a probabilistic orientation. Our effort has been to use the computer directed terminal to allow the physician to code an initial decision tree. Such a decision tree, provided it starts with the right questions, can be constructed so as to use information describing the abnormality to eliminate a large percentage of the possible diagnoses and display a subset for serious consideration. In use, this decision tree brings the physician to a list of possible diagnoses that must be considered given his reply to questions generated by his path through the decision tree. The analyzed physician-experience with a large number of cases can be reduced to a kind of public model of the disease. Bayesian mathematics can then be used to analyze the possibilities provided at the termination of the decision tree and return the diagnosis with the higher probabilities. The computer assisted diagnosis programs available at the MARS terminal allow a resident to examine at each step of the decision tree the current probability for each relevant diagnosis. Hence the student of Radiology has an efficient means of examining the weight of each of the parameters of his decision. Assuming that both the decision tree and the probabilistic model of the radiographic specialty in question are produced by a person with outstanding expertise in his specialty the program represents the codification of his expertise. The decision tree represents the correct approach to the problem, the public model a kind of state of the art of probabilistic coding of the significance of each radiographic parameter. The program is useful not only in training but especially for clinical reference in the more rare specialties of radiology, such as bone tumors, where the average radiologist may not accumulate sufficient experience to have the realistic "feel" for correct probabilities which he exercises in his normal practice.

## BAYES' THEOREM

$$P(D_i/S=s) = \frac{P(D_i)\cdot P(S=s/D_i)}{\sum_{j=1}^{n}\left[P(D_j)\cdot P(S=s/D_j)\right]}$$

**The probability that a patient with symptoms s has a disease $D_i$ is directly proportional to the relative incidence of $D_i$ and to the frequency with which these symptoms occur in disease $D_i$.**

Figure 7. COMPUTER ASSISTED DIAGNOSIS. By proper use of computer mediated decision trees and Bayesian analysis MARS terminals provide training in estimation of diagnostic probabilities, a means of codification of radiologic expertise and assistance for rare cases where experience is insufficient to properly estimate disease probabilities.

## Direct Machine Diagnosis

The use of digital scanners and display allows the numerical representation of each picture point and the direct investigation in core of radiographs with the purpose of developing algorithms that locate portions of the anatomy, make significant measurements and then classify the measurements as normal or abnormal. A large part of the radiologist's time is consumed by normal and "uninteresting" picture classification. We are attempting to develop automatic screening programs to relieve the burden of such cases. Our principal success to date has been with brain scans, rheumatic heart disease, and congenital heart disease. None of the programs are clinically in practice but the three indicated are far beyond the basic research stage. They involve the use of large core machines and average about two minutes of 360-50 time per diagnosis. Results are presented in Figure 8 for a study of rheumatic heart disease comparing a team of radiologists with direct machine diagnosis.

The computer algorithm first "finds" the heart and outlines the area of consideration. Figures 9 and 10 show a case of congenital heart disease, an atrial septal defect, displayed on our Dicomed display terminal and the results of the computer search for the heart outline. After the heart is found, polynomials are fitted to portions of the left and right boundaries and a set of measurements taken. Measurement discrimination algorithms are then used to classify the set of measurements as abnormal or normal. Abnormal measurements are further classified corresponding to a differential diagnosis. The results in columns A, B, and C of Figure 8 represent different measurement classification algorithms. Training results represent success rate when the computer is allowed to adjust its own weighting functions based on the discriminating power of the measurements. Testing results are obtained with the weighting functions held constant on radiographs that the algorithm (in the fixed state) has not previously seen. The physician statistics represent diagnosis by a group of physicians using both the PA and lateral views. Only the PA view was used by the computer.

The results of Figure 11 were obtained by running the rheumatic heart program on a library of over 300 congenital heart radiographs. The algorithms that locate the heart were not changed, the same set of measurements and type of polynomial fits were used that successfully classified rheumatic heart cases. The higher success rate with ages of 0-4 years excluded points out that we have not yet adequately solved the scaling problems involved with the smaller radiographs. Results when all cases were excluded in which the computer missed the correct outline of the heart indicate also that a more general heart edge algorithm is necessary for congenital heart disease.

It must be emphasized that this study is not complete and the data is presented only to indicate usefulness of the digital display in creating and testing such automated programs. It is hard to forecast when such programs will be available for aid at the clinical level. We have taken an unlimited core, brute force approach to the problem. We are currently researching the means to automatically quantify the amount of pulmonary vascularity. It is impossible to specify at this point what is the minimum core size and practical hardware for a mass screening machine. It does seem safe to say that full resolution capabilities of our equipment will not be necessary.

RHEUMATIC HEART DATA

| | | | Testing | | | Training | | |
|---|---|---|---|---|---|---|---|---|
| | Number in Class | Radiologist | A | B | C | A | B | C |
| Class 1 Normal | 88 | 83 % | 89 % | 85 % | 88 % | 95 % | 94 % | 94 % |
| Class 2 MS | 33 | 50 % | 56 % | 24 % | 21 % | 82 % | 33 % | 33 % |
| Class 3 MI, MS-MI | 21 | 54 % | 24 % | 10 % | 10 % | 72 % | 14 % | 29 % |
| Class 4 Bivalvular | 87 | 29 % | 83 % | 72 % | 72 % | 82 % | 75 % | 70 % |
| Class 5 Aortic | 50 | 76 % | 59 % | 46 % | 48 % | 78 % | 62 % | 60 % |
| Total | 279 | | 281 cases | | | 282 cases | | |
| Overall Percent Correct Classification | | 62 % | 73 % | 61 % | 62 % | 85 % | 69 % | 68 % |

Figure 8. PHYSICIAN DIAGNOSIS COMPARED TO MACHINE DIAGNOSIS OF RHEUMATIC HEART DISEASE TEST LIBRARY. Computer training results refer to results on radiographs used to train or determine coefficients in decision algorithms. Testing results are for radiographs not seen by the algorithm. A, B, and C refer to different statistical discriminant algorithms.

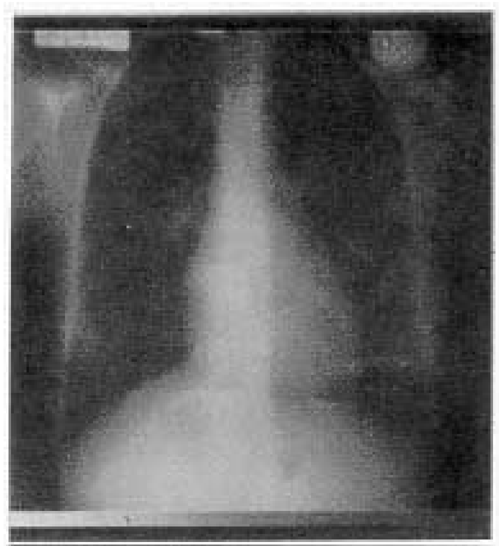

Figure 9. ATRIAL SEPTAL DEFECT DISPLAYED ON DICOMED DISPLAY. Congenital heart disease library currently contains over 300 cases. Patient is 20 year old male.

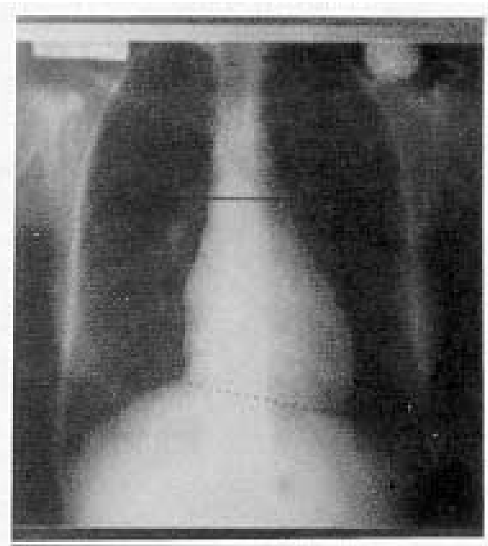

Figure 10. HEART OUTLINE FOUND BY COMPUTER. Same data as Figure 9 with outline of heart found by computer superimposed on display. Measurements are normalized with respect to thoracic width found by computer and taken with respect to midline of mediastinum found by computer.

CONGENITAL HEART

| | EXCLUDE 0-4 YEARS | | | ALL AGES | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total No. | No. of Hit | % of Hit | Total No. | No. of Hit | % of Hit | Total No. | No. of Hit | % of Hit |
| NORMAL | 61 | 55 | 90.16 | 97 | 75 | 77.32 | 90 | 70 | 77.77 |
| ASD | 61 | 43 | 70.49 | 70 | 38 | 54.28 | 68 | 40 | 58.82 |
| VSD | 43 | 13 | 30.23 | 73 | 26 | 35.62 | 71 | 28 | 39.44 |
| PDA | 15 | 5 | 33.33 | 35 | 7 | 20.00 | 34 | 5 | 14.70 |
| TETRAL | 13 | 4 | 30.77 | 28 | 6 | 21.43 | 28 | 5 | 17.86 |
| VENOUS | 16 | 0 | 0 | 19 | 1 | 5.26 | | | |
| TOTAL | 209 | 120 | | 322 | 153 | | 291 | 148 | |
| AVERAGE % OF HIT | | | 57.41% | | | 47.51% | | | 50.86% |

Figure 11. PRELIMINARY CONGENITAL HEART RESULTS WITH UNMODIFIED RHEUMATIC HEART ALGORITHM. Younger patients present scaling and normalization problems.

## Conclusion

It is safe to say that advances in medical radiant image management are now underway which during the next decade, will revolutionize the practice of radiology. These involve extensive changes in the methods of producing images, transmitting, storing and retrieving images, developing and evaluating images, extracting intelligence from images, and recording and delivering image information. These technological advances are coming on quietly, a little out of phase with each other, somewhat unsuspected by the medical profession, but they will come into bloom with a startling impact. They will permit better, faster, and more accessible medical diagnoses, and conceivably at less cost. Certainly their impact will be to change the patterns of radiological health care; yet beyond this, they will have an impact on industrial production and processing, in the sense of automated inspection and quality control. It appears that for the foreseeable future imaging will continue to be heavily dependent upon film as the most effective storage mechanism, although new laser technology could modify this as well. Much of this new technology is being developed and tested at Missouri, where already we are looking forward to the planning and execution of a new kind of health care facility which will optimize the application of these new technologies.

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