A POSITION PAPER FROM

SCAR

INNOVATING IMAGING INFORMATICS

Transforming Medical Imaging: The First SCAR TRIP™ Conference

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SOCIETY FOR COMPUTER APPLICATIONS IN RADIOLOGY

SCAR
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The Society for Computer Applications in Radiology (SCAR) is the longest-serving resource for imaging professionals interested in the current and future use of computers in medical imaging. SCAR is devoted to the advancement of computer applications and information technology in medical imaging through education and research. The Society provides an open environment in which imaging information professionals can access expert and cutting-edge resources in a collegial, practical atmosphere. A fundamental role of SCAR is to bridge the gap between the engineers and scientists who develop information systems and the radiologists and technologists who use them.

Membership in SCAR is open to anyone with an interest in the vital and growing field of electronic medical imaging and information systems. SCAR facilitates the growth and exchange of knowledge by and through: face-to-face interactions; an active scholarly and educational publication program; conferences and online education; consultation through the Expert Hotline; formation and support of user groups; and establishment of worldwide liaisons with appropriate computer and radiologic societies. SCAR's educational resources and expertise assist health information professionals in addressing the clinical applications and implementation of picture archiving communication systems, direct digital radiology, speech recognition, and emerging applications of digital radiology.

SCAR's Research & Development program has been active in identifying a pressing need to foster basic scientific research and reporting in the imaging informatics community. The first white paper on image compression was delivered at the first SCAR R&D Symposium in 2001. In 2003, the group identified the extraordinary increase in the volume of imaging studies as one of the most urgent problems in contemporary medicine. The Transforming the Radiological Interpretation Process (TRIP™) initiative was launched, and SCAR held its first TRIP™ conference in early 2005.

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Transforming Medical Imaging: The First SCAR TRIP™ Conference

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ABSTRACT

The First Society for Computer Applications in Radiology (SCAR) Transforming the Radiological Interpretation Process (TRIP™) Conference and Workshop, "Transforming Medical Imaging" was held on January 31 – February 1, 2005 in Bethesda, MD. Representatives from all areas of medical and scientific imaging academia, research, industry, and government agencies joined together to discuss the future of medical imaging and potential new ways to manage the explosion in numbers, size and complexity of images generated by today's continually advancing imaging technologies. The two-day conference included plenary, scientific poster and breakout sessions covering six major research areas related to TRIP™. These topic areas included human perception, image processing and computer-aided detection, data visualization, image set navigation and usability, databases and systems integration, and methodology evaluation and performance validation.

The plenary presentations provided a general status review of each broad research field to use as a starting point for discussion in the breakout sessions, with emphasis on specific topics requiring further study. The goals for the breakout sessions were to define specific research questions in each topic area, to list the impediments to carrying out research in these fields, to suggest possible solutions and near- and distant-future directions for each general topic, and to report back to the general session. The scientific poster session provided another mechanism for presenting and discussing TRIP™-related research.

This report summarizes each plenary and breakout session, and describes the group recommendations as to the issues facing the field, major impediments to progress, and the outlook for radiology in the short- and long-term. The conference helped refine the definition of the SCAR TRIP™ Initiative and the problems facing radiology with respect to the dramatic growth in medical imaging data, and it underscored a present and future need for the support of interdisciplinary translational research in radiology bridging bench-to-bedside. SCAR will continue to fund research grants exploring TRIP™ solutions. In addition, the organization proposes providing an infrastructure to foster collaborative research partnerships between SCAR corporate and academic members in the form of a TRIP™ Imaging Informatics Network (TRIPI^{2}N).

Keywords:
Large data sets, radiological image interpretation paradigm, medical imaging informatics

1. INTRODUCTION

The Society for Computer Applications in Radiology (SCAR) began examining the increasing problem of the number of images making up current medical studies, the number of studies associated with each patient, and the number of patients seen per day in current electronic radiology practices as early as 2002. The TRIP™ Initiative (Transforming the Radiological Interpretation Process) was formally launched in June of 2004 to examine this issue of information and image data overload, and to provide a forum for discussion as well as an organizational infrastructure to seek solutions to this impending crisis.

The SCAR TRIP™ Initiative aims to spearhead research, education, and discovery of innovative solutions to address the problem of information and image data overload. The initiative fosters interdisciplinary informatics research on technological, environmental and human factors to better manage and exploit the massive amounts of data. TRIP™ focuses on the following basic objectives: improving the efficiency of interpretation of large data sets, improving the timeliness and effectiveness of communication, and decreasing medical errors. The ultimate goal of the initiative is to improve the quality and safety of patient care.

Interdisciplinary research into several broad areas will be necessary to make progress in managing the ever-increasing volume of data. The six concepts involved include: human perception, image processing and computer-aided detection (CAD), data visualization, image set navigation and usability, databases and systems integration, and evaluation and validation of methods and performance. The result of this transformation will affect several key processes in radiology, including image interpretation; communication of imaging results; workflow and efficiency within the health care enterprise; diagnostic accuracy and a reduction in medical errors; and, ultimately, the overall quality of care.

Initial papers put forward by SCAR review the historical background to today's information overload, defining the problem and assessing the literature that addresses challenges involved in finding solutions [1-2]. Subsequent articles refine the TRIP™ Initiative, suggesting specific areas of research in which solutions to the problem of image data explosion may lie, and describe SCAR's efforts to identify immediate and long-term solutions [1-3]. Communication of the goals and strategies of the SCAR TRIP™ Initiative has continued via formal presentations at scientific meetings and through discussions with individuals at the National Institutes of Health (NIH), National Institute of Biomedical Imaging and Bioengineering (NIBIB) and other government agencies, other imaging societies, and representatives of the medical imaging industry.

SCAR proposed sponsoring a scientific meeting as another mechanism for informing the medical imaging community about the problems facing the field, and for engaging scientists in finding innovative solutions. In an effort to stimulate interdisciplinary thinking, a series of focused plenary sessions of invited speakers was planned to include experts from areas outside of medicine discussing their approaches to dealing with large image data sets, as well as talks by invited speakers in each of the six key topic areas previously mentioned. Intended participants included radiologists and other physicians, biomedical engineers, biomedical imaging scientists, computer scientists, imaging informaticists, imaging physicists, information technology professionals, medical imaging industry personnel, and students or other professionals interested in the problem of very large medical image data sets.

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The two-day conference included plenary, scientific poster and breakout sessions covering six major research areas related to TRIP™. These topic areas included human perception, image processing and computer-aided detection, data visualization, image set navigation and usability, databases and systems integration, and methodology evaluation and performance validation. The plenary presentations provided a general status review of each broad research field to use as a starting point for discussion in the breakout sessions, with emphasis on specific topics requiring further study.

The goals for the breakout sessions were to define specific research questions in each topic area, to list the impediments to carrying out research in these fields, to suggest possible solutions and near- and distant-future directions for each general topic, and to report back to the general session. The scientific poster session made up of selected abstracts submitted by attendees provided another mechanism for presentation and discussion of TRIP™-related research. Summaries of the plenary presentations and breakout discussions for each of the six major research topic areas are detailed in the next section.

2. MAJOR RESEARCH TOPIC AREAS

The general session of the SCAR TRIP™ Conference and Workshop began with opening remarks by the conference chairs, Katherine P. Andriole, Ph.D. from Brigham and Women's Hospital, Harvard Medical School and Richard L. Morin, Ph.D. from the Mayo Clinic Jacksonville. Dr. Morin reviewed the problem at hand, and the history and goals of the SCAR TRIP™ Initiative. Dr. Andriole described the high-level concepts requiring innovative research in each of the six major topic areas, the medical imaging interpretation processes affected by TRIP™, and gave the charge to the breakout sessions to formulate recommendations as to the issues facing the field, major impediments to progress, and the outlook for radiology in the short- and long-term.

Invited experts from areas outside of medicine discussed their approaches to dealing with large image data sets in their fields of geography and aerospace. Andrew K. Johnston, M.A. from the Smithsonian National Air and Space Museum, Center for Earth and Planetary Studies described issues related to data explosion in remote sensing activities in his plenary talk "Seeing the Earth: Organizing Access to Geospatial Data". Horace G. Mitchell, Ph.D. from the Earth and Space Data Computing Division of Goddard Space Flight Center, National Aeronautics and Space Administration (NASA) detailed similar problems in his presentation "Large Information Volume Management in the Aerospace Industry". It is interesting to note that researchers and experts in fields outside of medical imaging have struggles similar to what radiology is experiencing in dealing with large image data sets. These two non-medical imaging plenary sessions were followed by presentations in each of the six major research topics identified by the TRIP™ Initiative.

2.1 Human Perception

Previous reports on the SCAR TRIP™ Initiative [1-3] have stressed that research in human perception will be required to develop a standard for image quality as well as a standard for displays. Objective methodologies for optimal image presentation and criteria from which to determine optimal presentation parameters will need to be developed based on diagnostic performance measures. Psycho-physical models for detection of abnormalities will need to be defined by understanding what is desired by an image observer, what properties of radiological images are most useful in their interpretation, and how these properties can be enhanced to improve accuracy of interpretation [1-3].

In her plenary session on human perception Elizabeth A. Krupinski, Ph.D. from the University of Arizona used mammography as an example to emphasize that approximately one radiological image perception event occurs every five seconds in the United States – just for mammography. She described medical image perception as a very complex activity involving interplay between vision and cognition, and requiring detection, classification and actionable decision tasks performed on highly variable lesions. Dr. Krupinski noted errors including false positives, false negatives and misclassifications can occur and are correlated with training, experience and environmental factors, as well as technical limitations, lack of cognitive information (i.e., clinical history, prior images), and cognitive overload. Inter- and intra-observer variation is large and non-uniform.

Supporting visual aids such as image processing, checklists and decision trees, CAD, multi-modality image fusion, the use of color and three dimensions may assist in overcoming some of the display device limitations put on vision. Dr. Krupinski suggested that observer performance can be improved through a better modeling of vision and cognition tasks in medical image perception, through better working environments, and improved research strategies, methodologies, tools, and performance measures.

Dr. Krupinski was joined by Harold L. Kundel, M.D. of the University of Pennsylvania to co-lead the breakout sessions on human perception. Group discussion focused on workflow, ergonomics, display technology, and environmental factors in the new digital reading room, and on building perception research programs around these issues. Setting baselines for current practice, understanding working issues such as presentation of information, impact of the environment and reader fatigue, and better understanding and control of image quality issues including the physics, psychophysics and diagnostic measures were all important areas requiring further investigation. Developing new methods for teaching interpretation skills and continuing competency testing beyond residency training were of interest to the group.

The impediments to achieving advances in human perception with respect to medical imaging mentioned by the breakout group centered around a general lack of funding for perception, performance assessment and training, and insufficient industry-to-end user connections. Other challenges noted were the use of analog screen-film as the gold standard, and the expensive and difficult to perform assessment paradigms used for perception such as receiver operating characteristic (ROC) measures. The group cautioned that "more data is not necessarily more images" – that is, better renditions can be simpler and more effective. Support for the development of statistical methodologies in addition to ROC tests that further incorporate perception and cognition, integration of modeling techniques, collaboration with other domains, and understanding the human before using it to guide "machine" development were potential positive steps toward solutions.

2.2 Image Processing and Computer-Aided Detection

Earlier SCAR TRIP™ Initiative papers [1-3] have suggested that research in image processing and computer-aided detection will be needed to develop computer aides for feature perception and to design the radiology workstation of the future, focusing on the human–machine interface. Future radiology display applications will likely have to implement computer aides, such as cueing, overlays, and annotation, into a broadly supportive workstation. Assists, including decision support, simple reminder techniques to help avert errors of omission, data mining capabilities, and access to reference libraries, will need to be incorporated. Human–machine systems for image-based diagnosis will need to take advantage of both human and machine capabilities, creating a system that as a whole will be greater than the sum of its parts [1-3].

Bradley J. Erickson, M.D., Ph.D. from the Mayo Clinic, Rochester delivered the plenary session on image processing and CAD. He described image processing functions as including not only "slicing and dicing" of images, but also enhancing, measuring and viewing modes for imaging data, and reminded participants that all CAD algorithms include image processing. He mentioned that several excellent image processing components are available, some in open source such as ITK, but that evaluations and solutions in clinical production are lacking. Dr. Erickson expressed that image processing will most definitely be an element of the strategy for interpreting medical imaging examinations with large data sets, and that CAD results improve with larger data sets.

Image processing and analysis or CAD algorithms are typically of two types: target-based such as object detection and characterization, and non-target-based including change detection methods and atlas-based morphometric approaches. Current target-based CAD applications include lung nodule detection in chest computed tomography (CT) images, virtual colonoscopy CT looking for luminal filling defects, and CT and magnetic resonance (MR) angiography for automated detection of aneurysms and assessment of atherostenosis. Dr. Erickson summarized that for some diseases the combination of a radiologist's interpretation and target-based CAD is superior to either the radiologist or the CAD algorithm alone. He noted that while several target-based CAD clinical products are available, the high false positive rate and implementation issues need to be addressed.

Non-target CAD is focused on screening studies, change detection in serial examinations, and quantitative morphometric methods for new types of diagnoses. Change detection identifies significant differences and simple image subtraction can work if image samples to be compared have low noise and can be aligned. Subtraction of chest projection radiographs is one example. Change detection is also useful in monitoring brain tumors, multiple, sclerosis, vascular disease, and dementia through multiparametric comparison of MR images. Dr. Erickson stated that change detection appears to be an effective strategy for image overload.

He believes that computer tools will provide radiologists the ability to make diagnoses not possible by visual review, but that complete replacement of the radiologist is unlikely. Leveraging CAD is critical to utilizing all the information available, and while validation is slowly occurring for more diseases, integration of CAD into the practice is essential. According to Dr. Erickson, impediments to more rapid advancement of image processing in the clinical arena include limited access to image databases with large numbers of cases for training and testing of algorithms, expensive and lengthy methods required and the lack of a gold standard to objectively measure performance, and the poor technological integration of image processing and CAD applications with picture archiving and communication systems (PACS).

Dr. Erickson was joined by Matthew S. Brown, Ph.D. from the University of California at Los Angeles to lead the breakout sessions on image processing and computer-aided detection. Participants in this group, including representatives from academia, government and industry, all felt that CAD has a major role to play in maximizing the amount of information being reliably extracted from radiological examinations; and that in fact without CAD and other visualization tools, the advancing modalities may not reach their full potential. They noted however, that while basic research in image processing and pattern recognition has been ongoing for many years, and the potential and demand for CAD exists in many clinical areas, only two clinical problems have FDA-approved CAD systems – mammography and lung lesion detection. Ensuing discussions centered upon why there is so little CAD in clinical practice and what can be done to advance research in and translation of CAD.

Impediments to progress identified by the participants were categorized as either developmental, validation or implementation issues. Overcoming developmental costs requires clearing numerous hurdles including team building, software development and image database issues. Image processing research requires multidisciplinary teams of computer scientists, engineers, mathematicians, statisticians, radiologists, physiologists and biologists for modeling, as well as multimodality and multidimensional analyses, followed by industry for commercialization of applications. Software costs are high so more open source infrastructure and toolkits are needed. A change in culture will also be necessary to overcome intellectual property, financial compensation and academic credit issues. Session attendees also mentioned the high developmental costs related to image databases including the collection of sufficient and diverse image data for training and testing robust systems, the need for multi-institutional sharing of data, and issues around informed consent and image anonymization.

Validation impediments listed by the breakout included poor existing standards and methodologies for system evaluation, and establishing clinical utility of image processing and CAD. Establishing whether or not the technology improves patient care and outcomes, as well as a poor understanding of the effects of false positives are such impediments. Implementation issues raised during the breakouts include poor integration of CAD into the clinical workflow, efficiency and completeness in that CAD typically only does a small part of the work required when interpreting a medical imaging examination. Further there is a need for standards and formats for collection of raw data. Recommendations by the group to meet the challenges of high cost and numerous steps along the research and development path involved data and code sharing, and a focus on validation of clinical utility, and standardization of task definitions, databases and evaluation methods.

2.3 Medical Data Visualization

Medical data visualization has been gradually transformed with the advent of digital imaging and the maturation of computer tools. Medical images were originally displayed in static form on film. This process migrated to dynamic display with softcopy viewing of digital images. Image manipulation, including modification of contrast and brightness, magnification, and different presentation formats, became possible. Interpretation of cross-sectional modalities evolved from viewing images tiled across the monitor, to stack or cine modes, to linked stack mode for 3D correspondence, all of which have now become routine visualization modes. Newer visualization techniques include multi-modality image fusion, maximum intensity projections, multiplanar reconstructions, 3D surface and volume renderings, and virtual reality representations. Exploration of new visualization techniques, perhaps adapted from other fields such as the entertainment industry, could prove useful in medical imaging [1-3].

The medical image data visualization plenary was delivered by Elliot K. Fishman, M.D. of the Johns Hopkins University Hospital. He noted that the term visualization was derived from "visual data analysis" to emphasize analysis and interpretation. He stressed that visualization creates the possibility of communicating large amounts of information to the human visual system, and that for radiology the tasks involve detection of disease, defining disease extent, determining etiology of the disease process, assisting in designing clinical management plans for the patient based on imaging findings, and following response to therapy.

Several things have changed over the past 20 years to affect medical image visualization. The quality and quantity of the available data has improved greatly since 1985 when cross sectional images were acquired in 4 millimeter (mm) thick sections reconstructed every 3 mm for roughly 65 slices covering 20 centimeters (CM), where as today images are acquired in 0.6 – 0.75 mm thick sections reconstructed every 0.4 – 0.5 mm for approximately 500 slices. The speed of data reconstruction on the scanner has increased from an average of 2 seconds per slice to 0.05 seconds, roughly 40 times faster. Scanner resolution has improved from over 1 mm in 1985 to under 0.4 mm in 2005. In 1985 images were rendered using shaded surface display techniques performed on mainframe specialty computers, while today volume rendering is used and can typically be calculated on a personal computer platform.

Dr. Fishman stated that image interactivity has become a reality and computer image processing technology will enjoy widespread diffusion into the medical community. The ability to acquire isotropic voxel resolution using multi-detector CT provides more information than is available on axial CT scans only. He emphasized, however, that volume imaging requires volume visualization.

Dr. Fishman gave examples of areas in which 3-D visualization is currently used. Oncology is one clinical specialty that is benefiting from advanced imaging visualization, as are Orthopaedics, Cardiology and vascular specialties. He warned that the availability of technology does not necessarily mean that it will be used, as change in clinical practice is difficult, and noted that more technological improvements are needed. Improved displays, increased interaction with the datasets "beyond the mouse", 4-D functional imaging, faster load times for larger datasets, and improved volume rendering algorithms are all areas requiring continued development. Dr. Fishman gave a charge to researchers and industry to create easier-to-learn and easier-to-use visualization techniques, with capabilities for real-time rendering of large datasets.

2.4 Image Set Navigation and Usability

Earlier SCAR TRIP™ Initiative papers [1-3] have suggested that future intuitive easy-to-use tools for navigation through medical image data sets may include increasing use of 3D and motion, virtual reality fly-throughs, and hand–eye cueing instruments. Hand-held devices may become more widespread for more efficient point-of-care delivery of information. Context-matching and voice-activated tools may also be further developed for the clinical arena.

The plenary talk on image navigation and graphical user-interface (GUI) design was given by Eliot L. Siegel, M.D. of the Baltimore Veterans' Administration Medical Center and the University of Maryland. He stated that the challenge for radiologists is to read more studies without sacrificing quality, all in the face of increasing image overload, increased complexity of datasets, increased demand, and declining reimbursements. Clearly the basic paradigm of radiology interpretation of images will need to change substantially over the next few years.

Dr. Siegel reviewed the evolutionary phases of radiologist image interpretation, which progressed from film as a display, to static and then dynamic softcopy display, to stack and linked-stack navigation modes, to multi-planar and volumetric navigation. He noted that the move to electronic image review requires better default display protocols, and that PACS vendors must improve the capabilities of user-defined intelligent image presentation templates. He warned that more studies need to be performed to evaluate the effectiveness and efficiency of the softcopy display tools already being used such as window and leveling and linked stack mode. With the use of multi-detector CT, stack mode becomes inadequate for review of the 300 – 500 slices acquired for routing chest or abdomen and pelvic CTs, and even less so for the 1,500 – 2,000 images acquired for CT angiography (CTA) run-off studies.

Dr. Siegel believes the key paradigm shift in radiological image interpretation will be volumetric navigation, multi-planar and 3-D imaging. Just as digital imaging disengages the process of acquisition, storage and display previously associated with film, volumetric navigation separates image review from the manner in which the images were acquired and reconstructed. While CT scanners for the most part acquire images in the axial plane, volumetric data allows the radiologist to review or navigate through the data in an unlimited number of ways. PACS that do not make the paradigm shift to volumetric imaging will not be able to keep up with the demands made by multi-detector CT and today's other imaging modalities.

Current strategies for coping with the image overload in CT include acquiring images using thin collimation and then reconstructing the images that are sent to PACS using much thicker sections. This can reduce the number of images being sent to PACS by 3 to 10- fold but limits what the radiologist can do at the general PACS workstation, often negating the value of the new generation scanners. Additional reconstructions or rendering can be performed by the technologists at the scanner, or technologists or radiologists can go to advanced processing workstations to navigate the image dataset in any plane at any thickness. These workstations are typically expensive high-end modality systems that are not well integrated with the PACS. This is a large barrier to the use of volumetric navigation.

Volumetric CT can be useful in viewing the pulmonary arteries, the colon, as a general survey of an area, or to portray anatomic structures such as the ribs that course in an oblique plane. Dr. Siegel noted that 3-D imaging raises several clinical controversies. Abdominal and thoracic sub-specialists, for example, wonder whether they are now "responsible" for detailed reporting of the now well visualized musculoskeletal system, spine and vasculature. What are the implications of this with respect to the time required to dictate a study and how these cases should be billed are at issue.

It is not yet clear what the impact of 3-D imaging will be enterprise-wide. Non-radiologists seem to appreciate and readily adapt to the more intuitive perspective provided by 3-D image representations, and they tend to use these representations in a variety of ways in their clinical practices. This may increase referrals to imaging departments for more studies, though some in radiology fear opening up access to volumetric datasets to non-radiologists may increase turf battles.

Dr. Siegel was joined by Paul G. Nagy, Ph.D. and Khan Siddiqui, M.D. all from the University of Maryland to lead the combined breakout sessions addressing visualization, navigation and GUI design. The group commented that visualization and navigation is not just about CT and 3-D, but requires presentation of all the information necessary to make effective clinical decisions without distracting the user, followed by information synthesis. End-users want more functionality but simpler user interfaces. The Internet and Windows and Macintosh computing platforms might be used as examples for usability standards. GUIs should be designed with the following in mind: usability, intuitiveness, consistency, adaptability, discoverability, appeal, configurability, efficiency, and user fallibility in mind. Metrics of usability include number of clicks, number of seconds, mouse travel, eye movement, number of errors, etc. Displays should be flexible enough to accommodate different types of users and different types of imaging examinations.

The breakout recommendations as to opportunities for future work include developing models and metrics for function task lists to read different case types, workflow guidelines for the appropriate use of thin slice 3-D, and standardization of acquisition parameters as well as a common language and best practice for hanging protocols. Billing practice guidelines will need to be adapted and 3-D image quality will require standardization. Default usability of basic imaging tools should be measured and recommendations given on how best to implement them. ROC studies should be performed to tie the impact of rendering algorithms back to diagnostic accuracy.

2.5 Databases and Systems Integration

Advances in databases and integration will be essential and may require open standards, continued evolution of the American College of Radiology (ACR) –National Electrical Manufacturers Association (NEMA) Digital Imaging and Communications in Medicine (DICOM) standard, and increased adoption of the framework Integrating the Healthcare Enterprise (IHE) in imaging systems. Greater acceptance of IHE concepts will facilitate the integration of hospital and radiology information systems with picture archiving and communication systems (PACS) as well as speech recognition systems. Real-time image processing at the PACS display and Web-based systems will be possible through better integration and database richness [1-3].

Steven C. Horii, M.D. of the University of Pennsylvania delivered the plenary session covering databases and integration. He addressed why databases and integration are so critical, the importance of information quality, what information is needed, and where radiology might find examples of good databases. Databases are how one finds the information that is stored, they determine how quickly the information can be retrieved, and affect the quality of the archived information. Dr. Horii noted that radiology is not an information island, but a part of the ocean. Integration of databases and systems can help to determine what information is needed that a user does not have. For example, what use is a radiological interpretation if the referring physician cannot get it in a timely fashion?

In the film-based paradigm, image retrieval was very manual and people-intensive, imaging prior examinations had to be located by the film librarian and patient laboratory results had to be viewed in the paper chart or ascertained by telephoning the lab. Radiology is being asked to be more productive today and the increase in size of imaging examinations precludes using the film paradigm. Databases can be useful in finding relevant prior examinations quickly, and in finding the key images within that prior quickly.

PACS databases today typically have rules-based prefetch algorithms for retrieval of relevant prior imaging examinations and may have key image directories and key image notes. Complex searches answering questions such as, "I saw a case like this 6 months ago and would like to compare with it" are more difficult, though the teaching file model works for some. Content-based retrieval, finding information based on content, not identifiers as a key will likely become more commonly used for medical information retrieval. Dr. Horii suggested that medical information systems could benefit from the Google model. Information searches on the web are very fast, and although a lot of junk is delivered, usually several relevant hits are quickly returned. Perhaps very fast retrieval of images with their reports could result in better diagnoses.

Dr. Horii mentioned that the quality of information stored in today's PACS is often lacking and can be lost altogether. Standards put in place such as the DICOM Modality Worklist feature can reduce the amount of erroneously entered data. Not knowing when an imaging acquisition is complete is a common problem in PACS resulting in degraded database integrity. As the numbers of studies increase and their sizes grow, avoiding database problems becomes more challenging. Dr. Horii suggested that automation can improve database information quality, as well as facilitate improved user interfaces, and preemptive detection of errors before they propagate. He stated that processes can be automated by integration. For example, imaging equipment should be able to update the PACS database with additional images, and billing systems must be able to request updates if accession numbers are changed. Information quality assurance procedures including read-after-write checks, DICOM Storage Commitment, DICOM Performed Procedure Step, IHE Profiles, and automated searches for unread studies can help.

Dr. Horii stressed that while PACS have improved access to imaging data, radiologists need other types of information that they do not have that could improve the specificity of diagnosis delivered in their interpretation. Information such as the reason for the imaging examination being ordered by the referring clinician, laboratory data, and patient clinical history, in addition to cross-specialty and cross-modality imaging is important. Decision support tools will provide more information to end-users, but needs to be more fully integrated into the PACS database.

Information transfer needs to be multi-directional so that referring physicians can find the information they need for patient management without having to login to radiology's systems. Dr. Horii believes that an enhanced electronic medical record (EMR) could be an information portal and an information-gathering agent, looking for difficult-to-notice trends. This requires access to multiple databases however, until a unified information system evolves. He reminded attendees that there are HIPAA concerns and protected health information restrictions, special needs for research projects, and a risk of information overload.

Dr. Horii put forward the question that as medical imaging storage requirements approach petabyte levels, are existing databases good enough; can they handle the number of transactions required in the integrated model? He suggested modeling medical databases after other successful large high transaction rate systems such as the Internet and the financial industry. He predicted that databases will grow at an exponential rate as will the number of transactions, and that information quality needs to be planned for as part of this growth, which can only be accomplished with integration across systems.

2.6 Methodology Evaluation and Performance Validation

Research in methodology evaluation and validation of performance will involve developing objective methodologies for radiological imaging as well as standard datasets for testing, comparison and collaborative research [1-3].

The plenary presentation on evaluation of methodologies and performance validation was given by Ramin Khorasani, M.D., MPH from Brigham and Women's Hospital, Harvard Medical School. He discussed the role of evaluation and the use of metrics in bringing about change in processes and performance, and stressed the importance of using information technologies to improve efficiency and the quality of medical care. He cited the Institute of Medicine's 2001 report "Crossing the Quality Chasm" [4], which calls for system changes that enable and promote the practice of medicine based on evidence so that medical errors and waste can be reduced and quality can be improved.

In order to evaluate methodologies Dr. Khorasani noted that first the problem the technology or the system is addressing must be identified and described and valid objective metrics defining success must be stated, with baseline measures determined. He described a framework for information technology benefits evaluation including first setting expectations, assessing adoption (will it be used), surveying end-users (do they like it), and measuring improvements in efficiency, quality, safety, etc. He warned that without valid metrics processes and systems cannot be changed, and support cannot be recruited for adoption or funding.

Engineering or technology evaluation metrics include latency and user interface assessment, functionality, turn-around time, system availability or uptime, data quality, adoption or usage, and user satisfaction. Evaluation metrics for clinical methods can also include patient satisfaction, referring physician satisfaction, utilization of medical services, order modification, treatment or management changes, medical error rates, and patient outcomes.

Dr. Horii was joined by Curtis P. Langlotz, M.D., Ph.D. also from the University of Pennsylvania to lead the joint breakout sessions discussing databases, integration and evaluation of methodologies. The group discussed optimal systems, the various databases comprising the electronic medical record, other information sources (i.e., Internet, PubMed), and tools for database federation. Desirable middleware functions listed were access control, customizable per user, standards use including DICOM, Health Level 7 (HL7) and Clinical Context Object Workgroup (CCOW), and role-based workflow-driven interfaces. Optimal database functionality should include delivery of the necessary information to the correct authorized individual, in the right place at the right time. Further, information should be proactively pushed similar to the "dashboard" model, and bookmark features and trigger functions should be embedded.

There are barriers to creating optimal databases with appropriate integration, some of which are technical, some behavioral, some organizational and some fiscal. Technical barriers include proprietary data formats and interfaces, lack of information, fault tolerance and system availability, lack of data retention guidelines, lack of metrics for data quality, and lack of communication among standards developers. Behavioral barriers noted are resistance to change, resistance to measurement, and concerns about discoverability. The breakout group listed organizational barriers to include turf issues, lack of communication among systems developers, poorly understood data needs of various users, and a lack of a database for outcomes research. Fiscal barriers discussed include the high cost of systems, the difficulty, complexity and cost of outcomes and return-on-investment studies, overzealous intellectual property protection, and a lack of research funding for methodology and systems evaluation.

Research topics identified by the group included content-based image retrieval, radiology terminology and ontology or lexicon, structured reporting, and many issues around determination of workflow. Clinical research topics were aimed at demonstrating that PACS and information systems in imaging improves patient care. Investigations of the impact of decision support at the time of study ordering on appropriateness and quality and cost of care is one example. It was noted that research funding is lacking in the support of engineering evaluation (benchmarking) and clinical evaluation (outcomes and management) research.

All in the breakout session agreed that integration is essential to high quality care and that integration is also vital to measurement, which in turn is essential for evaluation. Step-wise technology assessment is needed. Funding gaps for certain kinds of information technology research in radiology will need to be filled. The group recommended that SCAR continue to play a role in education of systems-based practice and evidence-based practice. They suggested that SCAR serve as a much-needed clearing house for collaborative studies, marrying data sources and research questions to data analysis systems, and to continue funding through the TRIP™ Initiative.

3. CONFERENCE DISCUSSION SUMMARY

For progress in transformation of the radiological interpretation process to be made, the interplay of concepts from each of the aforementioned areas of research will need to be explored. The result of this transformation will affect several key processes in radiology, including image interpretation; communication of imaging results; workflow and efficiency within the health care enterprise; diagnostic accuracy and a reduction in medical errors; and ultimately, the overall quality of care.

The overwhelming majority of the conference participants felt the program was beneficial to them in increasing awareness and understanding of current practices and problems in interpretation and management of large data sets, and further identifying opportunities for improving the efficiency of interpretation in clinical practice. Attendees felt the meeting helped them to become more aware of methods to facilitate coordinated interdisciplinary imaging research, to prepare for the coming challenges facing image interpretation and management, and to identify promising directions for future research in radiological informatics.

Meeting attendees felt the conference format with plenary sessions followed by breakouts was effective in realizing the goals of the SCAR TRIP™ Initiative, including defining the problem and promoting discussion of potential solutions. Participants expressed that the conference gave them excellent opportunities for interaction and enabled them to meet with a multidisciplinary cross-section of scientist and clinician leaders in academia, government and industry, as well as to network with other participants to explore new ideas. Conference registrants also enjoyed the poster session format and appreciated that attendee input was welcome. Participants did recommend that the breakouts tackle smaller more focused topics, and some attendees expressed an interest in attending multiple breakouts if the scheduling allowed that. These suggestions will be considered in planning the next SCAR TRIP™ Conference and Workshop.

Other benefits noted by participants included giving them a reference against which to measure new research approaches, making them better aware of the practical aspects of clinician workflow, and identifying areas for additional research and additional information sources. Industry attendees expressed that some of the outcomes of conference discussions encouraged them to partner with academic investigators. Corporate participants also mentioned that ideas generated at the SCAR TRIP™ conference would affect product planning for future advanced visualization workstations.

4. FUTURE ACTIONS

The First SCAR TRIP™ Conference helped refine the definition of the initiative and the problems facing radiology with respect to the dramatic growth in medical imaging data. It underscored a present and future need for the support of interdisciplinary translational research in radiology bridging bench-to-bedside. SCAR will continue to fund research grants exploring TRIP™ solutions. In addition, the organization proposes providing an infrastructure to foster collaborative research partnerships between SCAR corporate and academic members in the form of a TRIP™ Imaging Informatics Network (TRIPI^{2}N).

Perhaps the greatest deficiency in dealing with computerized imaging has been the tendency of practitioners to react on an ad hoc basis to innovations rather than working collaboratively on techniques and tools that will provide quantifiably useful and usable solutions to everyday clinical problems. End-users in radiology have been separated from researchers, industry, and from those in other medical and non-medical fields who are faced with similar data overload challenges. Building effective bridges among participants in digital imaging is essential to expediting the delivery of tools and practices to the clinical environment.

Sponsoring and encouraging research that provides durable solutions will continue to be a SCAR mission. Only research that arises from a solid understanding of the long-term needs of radiologists, patients, and information systems can hope to provide optimal solutions to the coming crisis in radiology. For this reason, SCAR proposes creating an infrastructure for interested parties including radiologists, academics, researchers, and clinician end-users to work closely with SCAR corporate partners in shaping the systems, tools and products to be made available for clinical use. The TRIP™ Imaging Informatics Network (TRIPI^{2}N) will provide an opportunity for corporate partners to work with a cross section of SCAR users, institutions and experts who will facilitate translational research, develop the methodologies for investigation into new solutions, and provide objective evaluation of product performance and study results.

SCAR will continue communicating urgent issues and new results to the larger community. Through formal presentations and publications, SCAR aims to provide a single source for dissemination of information and discussion of concepts among the wide, multidisciplinary audience interested in these issues. SCAR will be holding a TRIP™ Exapartner Forum in January 2006 for qualified SCAR corporate partners. It will be an open format intended to facilitate discussion between the TRIP™ Exapartners and SCAR experts. The emphasis will be on hearing the corporate point of view regarding the TRIP™ Initiative and the future direction of research and development activities in industry. A Second SCAR TRIP™ Conference and Workshop is planned for late 2006 or early 2007.

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