Innovations in Diagnostic Radiology

Edited by James H. Anderson

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Foreword

This volume of the new series, "Medical Radiology" addresses the important topic of "Innovations in Diagnostic Radiology". It presents examples of current work of interest not only to the radiological community but to physicians in other medical disciplines and to scientists in general.

The impact of radiology on diagnostic medicine and patient management has been obvious from the beginning of our specialty. However, the evolution of the field is expanding at an astounding rate. During the professional lifetime of one generation of radiologists alone, numerous technologies and procedures have been added to conventional radiography: cross sectional tomography, high resolution nuclear scanning, magnetic resonance imaging, ultrasound, interventional radiology and computer based radiological operations. The optimal interpretation of images obtained by these new technologies requires that we expand our knowledge in physiology, biochemistry and also in our clinical expertise. It also means that radiologists must collaborate closely with other clinicians and basic scientists.

Two introductory chapters set the stage for the current and future challenges in radiology and provide suggestions regarding the successful development of a research program in an academic department. The concept, as presented here, matured over a period of several years and in discussion with junior and senior members of our faculty as well as residents and fellows. When investigation into basic and clinical questions brings together members from different departments of the medical faculty, the Dean's interest in supporting a centralized research resource facility, particularly at its beginning, is heightened. Participation in basic, applied or clinical research should be considered a desirable feature of training programs in diagnostic radiology. The benefits of research experience to young physicians embarking on a career in radiology are numerous, regardless of ultimate career choices. From imaginative investigation of pathophysiological events and of organ involvement in localized or systemic disease, to taking an active role in development, modification, or application of new equipment, time in the research laboratory is well spent as part of trainees' education in radiology.

Whether working alone or as a member of a team, whether results of a project are positive or not, the process of acquiring new knowledge is exciting. The frustration over a failed experiment is a powerful motivator to rethink and perhaps redesign one's experimental approach. The process promotes step by step logical thinking which is carried over in one's clinical work. If followed by success, the investigator's reward are feelings of accomplishment; research induces enthusiasm. Benefits of a good research program collaborating with colleagues from other clinical disciplines or with basic scientists are high motivation, good morale and esprit de corps. These characteristics are almost invariably carried over to the clinical setting. Joint work in research stimulates closer personal ties in patient care.

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Preface

Within the past ten-twenty years, technological advances have dramatically changed the image, responsibilities and functions of the diagnostic radiologist. These changes are reflected in a renewed concern for academic department planning relating to patient care, teaching, and research. The antiquated service function image of the radiologist sitting in a room reading stacks of films is being replaced by one of a new breed of radiologist who is more actively involved in the development and application of technology and who participates more actively in the care and management of patients. The computer era and the increasing concern for reducing medical care costs have created both opportunities and concerns for current radiology planners and leaders as well as for the bright young radiologists and trainees who will be the leaders of tomorrow.

Developing individual career objectives or long term departmental plans requires a vision of what the future may hold for diagnostic radiology as a discipline, and for the various imaging and therapeutic modalities currently available as well as for those under development. This volume addresses some of the topics that may contribute significantly to the future of diagnostic radiology. In compiling the chapters, the authors have tried to address the current state of the art and discuss the potential future development of their area of expertise.

The first two chapters of the book discuss current and future challenges for academic radiology and radiology research program development. Both subjects relate directly to the academic growth of diagnostic radiology departments and the continued research and development of the imaging techniques or procedures discussed in the remaining chapters. Chapters three and four are concerned with image analysis techniques and three dimensional image reconstruction. Both areas are receiving increased attention through the use of more powerful computing capabilities and both will receive considerable attention during the next decade. The Nuclear Magnetic Resonance imaging chapter (Chapter 5) provides information regarding the basic principles of magnetic resonance imaging and discusses various Nuclear Magnetic Resonance imaging techniques. Emphasis is placed on developmental trends and potential applications. Nuclear Magnetic Resonance spectroscopy is an area that will receive intense investigation over the next decade and Chapter 6 discusses its current and future role in monitoring tumor growth and response to therapy.

Positron Emission Tomography provides opportunities to image and map functions such as tissue blood flow, blood volume, glucose uptake, protein synthesis and neuroreceptor binding. These topics and others are discussed in Chapter 7. Since its relatively recent introduction, Interventional Radiology has placed the diagnostic radiologist in the unique role of treating patients. This area is now recognized as a true sub-specialty, and Chapter 8 outlines some of the important emerging areas that will be further developed and refined in the near future. The increasingly important diagnostic applications of ultrasound is presented in Chapter 9. The last two chapters of the volume present applications of imaging techniques to study cardiac wall motion and new approaches to CT guided stereotactic brain surgery.

The composition of diagnostic radiology department faculty is becoming more heterogeneous as new technologies emerge and both basic scientists and non radiologists find imaging to be an exciting and important modality in both research and patient care. This diversity in expertise is reflected in the background and training of the chapter authors of this volume. Contributing authors have received formal postgraduate training in such areas as radiology, physiology, mathematics, psychiatry, computer science, biophysics, biochemistry, cell biology, nuclear medicine, electrical engineering, biomedical engineering and neurosurgery. This mix of basic scientists and clinicians working together in collaboration to advance the state of the art in medical imaging should be welcomed and encouraged. It will strengthen the research and development as well as the patient care and teaching components of academic diagnostic radiology departments.

The future for diagnostic radiology is very bright and for this reason, the discipline is attracting some of the most gifted medical school graduates and basic scientists. The contributors of this volume will consider their efforts rewarded if the book helps to stimulate the younger clinicians and scientists seeking direction in a career in imaging and assists in guiding the more senior clinicians and scientists in directing the academic growth and development of their departments.

JAMES H. ANDERSON

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1 Current and Future Challenges for Academic Radiology

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1.1 Introduction

During the past 10-15 years, clinical medicine and medical research have experienced an unprecedented technological growth. Of all the medical disciplines, diagnostic radiology has likely experienced the greatest impact of this growth. The introduction of computerized axial tomography, for example, demonstrated to the Radiology community the practical application and utility of computer-assisted image acquisition, processing, presentation, and analysis. This major advance, along with the introduction of magnetic resonance imaging (MRI), in vivo nuclear magnetic spectroscopy (NMR), positron emission tomography (PET), digital radiography, and interventional radiology, has dramatically altered the manner in which the radiologist in particular and radiology departments in general function in patient care, teaching, and research. These advances provide diagnostic radiology with unique academic growth and development opportunities that are more available now than ever before.

Indications suggest that medical imaging technology research and development will continue at an even faster rate than previously experienced. As a result, the issues that must be addressed by radiology departments are more complex than those present 20 years ago. At that time, radiology was almost entirely a film/screen-based technology and regulations for health care delivery costs were not focusing attention on high-cost computer-based image technology. In the late 1980s radiology has come to a crossroads; consequently academic departments are now faced with critical decisions that will significantly affect how their discipline will function in the future. Many of the issues that must be addressed now and in the future affect all medical specialties and are not unique to radiology. In fact, because recent advances in medical imaging have made such a positive impression on the medical community and the general public, diagnostic radiology, more than any other specialty, is in a very favorable position to capitalize on the issues in order to further improve academic growth and recognition. Indeed, the future for diagnostic radiology has never been more promising than it is today.

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1.2 Economic Issues

Academic radiology departments are responsible for providing high-quality patient care as well as innovative teaching and research programs. Currently, these needs present themselves at a time when economic and social changes in the health care system are placing an increased fiscal burden on academic institutions which are already stressed financially. Academic departments are being asked to economize and restructure clinical services in an attempt to conform with federal regulations on increasing health care costs, the competition of an increasing number of HMOs, the high costs of diagnostic procedures, and cutbacks in medicare reimbursement for teaching and administrative duties. At the same time, university-based radiology departments need to become even more academically oriented and to participate more aggressively in the development and application of new technology. This issue represents a significant opportunity for diagnostic radiologists to exert influence and become more academically involved in defining the true cost-benefit ratio of new imaging techniques. Research funds for such studies are becoming more available.

At the present time, the entire medical community is still somewhat overwhelmed by the relatively recent surge in the development and application of new imaging techniques. Clinical applications of imaging technology are still in their initial growth phase, with the developments occurring rapidly. It is difficult to predict which developments and applications will survive the test of time and which will be able to improve patient care at a cost compatible with the inevitable restructuring of health care costs in the future. This difficulty in forecasting was addressed at a recent international symposium on the impact of new imaging technology on health care, research, and teaching, in which a prevalent theme was the need for comprehensive investigation of the economic implications of new imaging technology (FIGLEY and MARGULIS 1987).

Radiologists must make it their responsibility to scrutinize procedures, techniques, and imaging modalities. They must begin to differentiate between studies that provide meaningful diagnostic information or therapeutic value and studies that provide "pretty" images or information which can be obtained from other less costly methods. Such evaluations will take considerable time, effort, and money, and funding agencies will be prepared to share the costs. For example, the clinical and/or economic value of a new interventional procedure often will require extensive long-term follow-up studies to compare its clinical and economic value with more readily available procedures.

1.3 Image Analysis

As imaging technology becomes more sophisticated and more readily available, the manner in which the radiologist views and interprets images will undergo many changes. In a recent article discussing Future Advance and Directions in Imaging Research, Dr. WALTER ROBB (1988), Senior Vice-President for Research and Development at General Electric, stressed the importance of converting data into information. This paper addressed new opportunities in the fields of digital signal processing, computer-aided imaging and analyses, and artificial intelligence. Dr. ROBB stressed the fact that well funded application research outside of medicine will provide new technology that will have direct application in medical imaging (ROBB 1988). Investments in image analysis technology for both clinical and basic science research can be funneled to enhance or support the routine clinical needs such as transmitting and storing images. Digital radiography may be able to tighten referral networks and help secure hospital patient bases by linking community physician activities and reports to a central digital image system of the hospital (WAGNER 1988). Financial, space, and personnel investments in image analysis cannot help but benefit both research and clinical components in departments of radiology.

As they become more involved in functional imaging, radiologists are introduced to an entirely different data set and approach than previously available through conventional film/screen-based systems. This will provide new areas for academic growth and expose the radiologist to new approaches to become more actively involved in the care and management of the patient. The radiologist will begin to better utilize computer algorithms to analyze images for information about organic disease in addition to information about anatomical detail. Providing functional information such as blood flow, energy metabolism, and oxygen and glucose consumption obligates the radiologist to become increasingly more involved in evaluating the disease process itself. This transition will continue to occur in virtually all areas of radiology.

1.4 Department Divisional Structure

The organization of departments with regard to subspecialization is being reevaluated. The advantages and disadvantages of an organ/system structure versus an imaging modality (technique) structure need to be reconsidered. The increasing emphasis on providing information about the disease process itself and the integration of multidisciplinary components in radiology faculty will also require reevaluation of departmental training programs. Neuroradiology has already addressed this issue by extending fellowship programs to 2 years and pioneering an organ system approach in which neuroradiologists perform angiographic and neurointerventional procedures (POTTS 1988).

1.5 Radiology Training

Radiology departments within academically oriented institutions must take a leadership role in providing both specialized and subspecialization training programs which have emphasis on academic research and teaching. University administrators expect no less and those academic institutions with appropriate resources must set an example for the entire discipline of radiology. A chief mechanism through which they can address this responsibility now and in the future is through aggressive development of academically oriented research training programs. Strong academic institutions should provide academic resident and fellowship programs which are not directed at producing general radiologists. The opportunity for diagnostic radiology departments to provide academically oriented training programs is becoming easier as more emphasis is being placed on extramural funding of medical imaging research.

Although other clinical disciplines such as surgery and cardiology often require research training as part of residency or fellowship programs, radiology has usually not required formal rotations aimed specifically at providing research training or formal exposure to research. For this reason, radiology has fewer physicians actively engaged in careers combining clinical work and basic research as compared to other specialties. Because other disciplines have had such programs in existence for some time, residents and fellows in these specialties accept them as a structured requirement of the training process. Attempts to incorporate formal research training in radiology, on the other hand, are often met with resistance from both faculty and trainees. Continuation of this attitude will not only undermine the academic credibility of radiology in the minds of the university administrators and members of other clinical departments but will also jeopardize the ability of the radiologist to compete with other clinicians for extramural peer-reviewed research funding. Because of increased competition for extramural funding, it is more essential now than ever before that this situation be corrected and research be included in academic radiology training programs. Implementation of a strong research training program requires an environment conducive to academic growth and this requires careful planning with specific short- and long-term goals. Immediate and thoughtful attention must be given to this subject. Important justification for this includes:

1. Radiologists must compete with other medical disciplines in basic research involving the development and application of imaging technology. Although the National Institutes of Health (NIH) provided $ 137 million for medical imaging research in 1987, a substantial amount went to disciplines other than radiology (Hendee 1988). The grant money is available and although awards are very competitive, the opportunities for funding have never been better. More radiologists and basic scientists are receiving training in new imaging technology. Within a relatively short period of time, diagnostic radiology departments will start receiving a greater share of these grants.
2. Because of the recent advancements in imaging technology and interventions, radiology is attracting more of the brightest medical students into residency programs. To maintain this momentum, it is important for academic radiology departments to provide these trainees with superb clinical training, as well as an academic teaching and research environment which will not only advance their own academic careers but will contribute to improvement in the state of the art of medical imaging. Because the national trend shows a decline in the number of students entering science and medicine, radiology may be unique among the specialties in attracting these bright, young scientists and physicians (Weaver 1988). This represents a major positive factor for the future academic growth of radiology.
3. The capability of radiology departments to retain control over imaging studies will depend on their academic and research credibility relative to that of clinicians in other departments. Radiologists are becoming more aware of this and positive steps are being taken to improve training programs to prepare radiologists to become more academically competitive.

1.6 Loss of Academic Radiologists

Radiologists should be concerned that so few residents and fellows who leave academic training programs ultimately pursue academic careers. Although the financial burden of a medical school education and the physical burden of extended residency and fellowship programs may tend to "burn out" many individuals, the lack of academic role models in the radiology faculty also contributes to the loss of academic radiologists. In addition, many clinical and research faculty members who serve as role models are themselves leaving academics for private practice largely because of financial considerations and the lack of adequate research time and/or facilities (Hess 1988). This situation is not unique to radiology. The opportunities for academic career development in diagnostic radiology have been significantly enhanced with the growth of interventional radiology, computer-assisted imaging, and NMR/MRI. If role models are leaving academia for private practice because of a lack of research time and/or facilities, inadequate attention has been given to developing an environment conducive to academic career development. This is an issue that must be addressed by all academic clinical departments.

1.7 Integration of Basic and Clinical Research

Although most research and development of hardware and software will be accomplished through industrial efforts, applications research and probing questions of biological or medical significance will be, as always, the domain of academic institutions. The responsibility inherited in this task requires a major effort to integrate basic and clinical research. It also requires the cooperation and collaboration of physicians, biochemists, engineers, physicists, physiologists, statisticians, mathematicians, computer programmers, and biologists. During the past 12 years, as many Ph. D. basic scientists have been appointed to clinical departments in the United States as have entered basic science departments in medical schools (McKneally et al., 1986). Radiology departments and many nonimaging specialists are actively and aggressively recruiting basic scientists into faculty positions. As new people are recruited into radiology departments, major decisions will need to be made about program development and investments in salaries, equipment, research projects, and space. Decisions will also need to be made about the specific areas most worthy of pursuit and the intregration of the research with teaching and patient care activities.

An active, productive research program enhances both the teaching and clinical care activities of a radiology department. However, research programs must be fiscally responsible. Funding levels for basic research often cycle with changes in funding priorities. This normal fluctuation should be expected and anticipated. However, departmental support of research for which there is continued lack of peer-reviewed funding creates financial and morale problems for clinical departments and does little to enhance academic credibility in the view of university administrators and other non-radiology-based clinicians and basic scientists.

The importance of research in medical imaging was recently summarized by Dr. Ross Weaver of the Office of Technology Management, American Medical Association. Dr. Weaver strongly feels that research in radiology is an important national resource. He said, "The priorities are clear: actively recruit the brightest and the best, fight to protect funding sources, and demand that the research equipment be updated and modernized. The time to begin is now, for there is a great deal to lose by the research environment in particular, and in the health of the American people in general" (Weaver 1988).

The role of the basic scientist in radiology departments will expand while the training and diversity of departmental faculty members will change as more basic scientists are needed to support the technological developments that will continue to impact on the growth of radiology. This trend will not only continue but will also become more important than ever before for full integration of the interests and activities of these individuals with clinical faculty. To be able to pursue and develop ideas to bring benefits to patients, basic scientists must be exposed to clinical problems. If these basic scientists fail to be integrated into the academic program, and if their activities are not combined with those of the radiologists, they will align themselves with clinicians from other departments who have financial and scientific interest in medical imaging. Although multidisciplinary interaction is scientifically valuable and should be encouraged, it should not be the result of alienation of the basic scientist by the clinical radiologist. In many instances the basic scientist can act as a bridge linking radiologists with other clinicians who share common research interests.

1.8 Enhancing Academic Image

There is no doubt that the development and application of new technology will progress, with or without radiology. If radiology departments do not recognize this, the credibility of the radiologist will deteriorate while imaging techniques and patient populations will be usurped by other medical disciplines. Further growth mandates that radiology departments structure their academic programs in a manner similar to those of other clinical disciplines. Although this restructuring may require a change in philosophy, it should not compromise quality clinical care or place heavy financial burden on the radiology department.

The tendency for radiology departments to be looked upon as primarily "service departments" has previously diminished university administration support for radiology research. University administrators are beginning to expect more from academic radiology departments because of the recent advances in imaging technology, the infusion of more basic scientists in radiology, and the interest that nonradiology departments are showing for imaging and profitable interventional procedures. Federal funding for imaging research has increased significantly over the past 15 years and more radiology departments are obtaining federally funded research training grants to assist in research training for both the basic scientist and the radiologist. NIH funded $ 137 million for medical imaging research in 1987 (WEAVER 1988). This represents a nominal increase in funding dollars of 10% annually for the past 10 years. Grants supporting radiology research have increased in number at a rate of 6.1% annually during the past decade (WEAVER 1988). Basic scientists within radiology are beginning to compete more actively for federal-funded research support of work in which radiology clinicians are becoming increasingly involved.

The time for radiology departments to establish stronger academic programs and provide proper role models for the younger trainees has never been more opportune than it is today. Departments must meet this challenge by providing the environment and incentives conducive to academic career development of faculty members. The challenge to improve the academic functions of radiology departments and the need to develop and reward role models cannot be ignored if radiology is to be actively competitive in the years to come.

It is time basic scientists and clinicians in radiology stop complaining and start competing. Many of the most important contributions in medical science and patient care during the past two decades have involved imaging. Innovations in diagnostic and therapeutic radiology will continue to be made, much to the increasing appreciation of the medical and general public. Radiology is attracting the brightest young scientists and physicians. Now is the time to channel their energy in a productive manner into further expansion of imaging and imaging research. The future of these young people should be the future of radiology; this should not be compromised nor their energy and enthusiasm dampened. The time has never been better for academic radiology to flourish. The future of the discipline depends on radiology departments assuming a more active responsible role in training future academic radiologists who will continue to expand the field.

Those factors that may strengthen or weaken the role of academic radiology as a discipline will affect all aspects of departmental programs, including patient care, teaching, and both clinical and basic research. Economic issues, technology development and application evaluation, departmental divisional structure, training programs, integration of basic and clinical research, and academic image all relate to one another and cannot be addressed as separate issues independent of the others.

The remaining chapters in this book address more specific areas of imaging with an emphasis on future development and application. The manner in which these technologies enhance the future role of radiology in patient care is dependent to a large degree on the manner in which they evolve in relation to many of the issues discussed in this chapter. Ultimately, the crossroads at which radiology sees itself can be traversed successfully, but only if radiology departments within academically oriented institutions assume the leadership role intended for them and take advantage of this "window" in time when opportunities for academic growth and achievement are most apparent.

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2 Diagnostic Radiology Research Program Development

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2.1 Introduction

Providing recommendations regarding developing and maintaining radiology research and research training facilities is a difficult task because no two departments have the same goals, resources, commitment, faculty composition, or philosophy. There is no ideal model and every department must address issues specific to their own particular goals and needs. However, concern has been generated in the radiology community regarding the role, development, and expansion of research programs and many of the issues that need to be considered are germane to all departments. The primary purpose of this chapter is to provide information which may be of value to the reader charged with the responsibility of addressing research-related issues in a clinical radiology department.

The decision to develop or expand the research program in any clinical department must be made with a firm understanding of the degree of commitment that is necessary. This commitment must permeate throughout the entire department and be part of a larger commitment to total academic excellence stressing superior patient care, teaching, and research. The success of a program will eventually be judged on the quality and not the quantity of work. The research program must be an integral part of department activities, and form a symbiotic relationship with clinical and teaching components. Although high-quality, clinically relevant research does not necessarily require major resources, it does require a strong departmental commitment to ensure its excellence and to maintain its proper perspective in the department and the institution.

During the past 15 years, the manner in which radiology departments view the development or expansion of research facilities has changed. This change has largely been related to the significant rapid advances in medical imaging technology and the manner in which these advances have altered the role of the radiologist in patient care and the training and composition of departmental faculty. When visiting radiology departments 15 years ago, it was not uncommon to be guided through one or two small, cramped rooms that constituted the "dog lab" or "physics lab." These facilities were usually used by one or two faculty members. In most cases, the laboratory did not constitute an integral part of an established, goal-oriented departmental research

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program. These laboratories were usually equipped with secondhand or discarded clinical equipment and staffed by technicians who had additional responsibilities as X-ray technologists in the clinical department. Funding almost always came from clinical revenue or industry and very few received support from extramural peer-reviewed sources such as governmental agencies, foundations, or large private funding sources. However, the radiology researchers were usually very dedicated and much of their work laid the foundation for modern-day applications such as in interventional radiology. At that time, most radiological imaging involved film-screen technique, research was not a major focus in most departments, and university and hospital administrators did not look upon most radiology departments as research-oriented resources.

Although such facilities still exist today, the trend is changing towards many radiology departments being concerned with developing more active, comprehensive, and formal research and research training programs. This involves major financial investments for renovation, equipment, personnel, and space. However, if some individuals are discouraged from developing or supporting a major research program because of the potentially prohibitive cost, the following factors should be considered:

1. People and not equipment or facilities are responsible for successful research programs.
2. Well designed clinical and basic research projects in medical imaging have a much greater chance of receiving extramural funding than was the case 10–15 years ago.
3. Most successful radiology research programs focus attention in only one or two specific areas of work.
4. Government research funding agencies will usually reimburse equipment use and maintenance fees for expensive imaging equipment used for research.
5. Multidepartmental generated funds can be a major source of income to purchase equipment and finance technical support salary.
6. Industry often provides reduced purchase prices or even free equipment for research laboratories.
7. The university and other departments benefit both academically and financially from image research laboratories and should help provide funding.
8. Highly successful, productive, clinically applicable research can still be done in relatively simple facilities. For example, good basic research in interventional radiology can be performed with X-ray equipment including little more than a fluoroscope, an overhead tube, and a film changer.
9. Strong academic programs with well equipped research facilities will attract academically strong clinicians and basic scientists who can support their own research projects through extramural sources. Strong academic programs attract strong academic people.

Because of the diversity of departmental goals, capital, and research interests, it is impossible to make specific recommendations regarding space, equipment, and personnel needed to develop or expand existing facilities. However, careful consideration must be given to space and equipment requirements not only for the immediate needs but also for those of the future. One of the most important factors to consider in planning radiology research facilities is maintaining flexibility and balance to meet changing needs relative to technology development, faculty research interests, and funding sources. Although some departments have invested heavily in personnel and resources directed towards a single specific area such as digital angiography, magnetic resonance imaging (MRI), and interventional radiology, it is those programs that maintain flexibility and balance that will continue to be productive over an extended period of time. If properly planned, this can be done without diluting areas of research that may experience temporary but clinically important periods of intense investigation. Investing heavily in research and development during this initial technology and application research phase can be highly productive and rewarding. However, if such investment totally jeopardizes other more conventional areas of work, the long-term results may not be in the overall best interests of the department or faculty.

If major investments in manpower, equipment, and facilities are heavily directed towards a very specific area of work, the results should be designed to benefit other clinical and basic research areas in the department. For example, computerized image acquisition, presentation, transfer, and analysis will form an important contribution in radiology departments of the future. This applies not only to larger academic institutions but also to the smaller community hospitals. Radiology departments cannot ignore the importance of this developmental trend. Research and development investments in image analysis will have widespread application in all clinical and research areas of the department. If academic institutions invest in cen-