Anniversary Paper: Roles of medical physicists and health care applications of informatics

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Over the past 100 years, both diagnostic radiology and radiation therapy have grown from infancy to maturity. Accompanying this growth, the discipline of medical physics has evolved and advanced accordingly. New diagnostic and therapeutic procedures continue to be developed, for example, multidetector computed tomography, multileaf collimation, magnetic resonance imaging, dual-source computed tomography, and intensity-modulated radiation therapy. These are now incorporated in health care facilities throughout the world. Modern technologies such as these provide information on underlying pathology at increasingly higher resolutions, generating more information; thus requiring complex methods of image recording and storage. The management of the storage and retrieval of accumulated information is a domain of informatics. In this short review, we describe the different roles of medical physicists and the effective contribution of the American Association of Physicists in Medicine in the evolution of informatics. Medical physicists have contributed to the development of informatics in numerous ways, such as designing hospital information systems and infrastructures that better serve radiologists and other physicians. In addition, the positive exploitation of knowledge gathered in medical settings and effective interdisciplinary collaborations between scientists of different backgrounds have increased. These developments provide future medical physicists the opportunity to develop strategic roles in information technology and thus better contribute to health care. [DOI: 10.1118/1.2822875]

Key words: medical physicist, DICOM, EMR, HIS, IHE, PACS, RIS

I. INTRODUCTION

Medical Informatics has been defined as "the field that concerns itself with the cognitive, information processing, and communication tasks of medical practice, education and research, including the information science and the technology to support these tasks."[1] It lies at the intersection of information science, computer science, and health care, and deals with the resources, devices, and methods required to optimize the acquisition, storage, retrieval, and use of information in health and biomedicine. At present, the operation of a hospital without the aid of integrated information technology (IT) systems is impossible. Such systems organize the collection, management, and distribution of all information from a variety of sources necessary for the efficient provision of health care. In many cases, medical physicists in radiology and radiation oncology departments have had a role in the management of IT systems, and these health care practitioners have evolved to become local IT experts. The scope of future roles and the degree of responsibility assumed within them by medical physicists constitute an interesting topic, currently discussed within our scientific community.[2–4]

Herein we mark the 50th anniversary of the American Association of Physicists in Medicine (AAPM) by describing the role of medical physicists and the AAPM in health informatics. In Secs. II and III, we describe issues related to informatics in both diagnostic radiology and radiation oncology. In Sec. IV, we present clinical standards in diagnostic imaging and radiation oncology. Section V discusses issues related to patient data protection. Section VI focuses on integrated picture archive and communication systems (PACSs) and hospital information systems (HISs). Section VII addresses the role of medical physicists in telemedicine and telecare. Finally, Sec. VIII describes the relationship of medical physicists and the AAPM to health informatics,

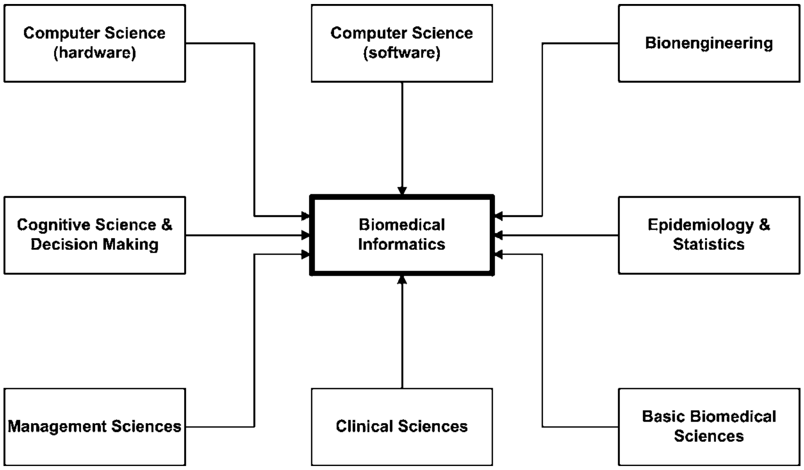

FIG. 1. Chart depicting medical informatics as a culmination of different fields that apply information technology in medicine [used with permission from Shortliffe and Cimino, (Ref. 5)].

while at the same time offering recommendations for providing medical physicists with the expertise needed to become local resources in health informatics.

II. INFORMATICS IN RADIOLOGY

Diagnostic medical physicists have a long history of providing technical leadership in radiology. As digital imaging in radiology has shifted away from film-based processes, the need for technical leadership has shifted toward IT. Today, radiology is critically dependent on information systems to function, and many physicists have acquired the expertise to provide such leadership in informatics. As a physicist's role is to understand the principles of physics to help physicians diagnose and treat patients, the role of informatics is to understand the principles of computer science to help physicians leverage information technology to be more efficient and accurate in their ability to diagnose and treat patients. There is a large cultural difference between IT professionals and clinical staff, which frequently leads to miscommunication and frustration. Informaticists work as liaisons to physicians and clinical staff translating requirements when working with internal support organizations and external vendors in the design and implementation of innovative IT solutions to clinical problems. This is very analogous to the role of a medical physicist acting as a liaison between physicians and an engineering support organization or vendor. In addition, informatics skills can greatly improve the physicist's ability to perform quality control and research by easily accessing clinical information systems.

Shortliffe and Cimino[5] have constructed a model that defines the discipline of informatics in medicine as "a culmination drawn from different fields to apply information technology in medicine" (Fig. 1). We have applied this model to imaging informatics, a field that has direct relevance for medical physicists in radiology. There is considerable overlap between informatics discipline and that of the physicist. The informatics discipline has considerable overlap between informaticists and physicists. The medical physicist has prerequisite knowledge of basic biomedical science, epidemiology, statistics, and bioengineering. Furthermore, the medical physicist possesses a clinical knowledge of anatomy and physiology, and direct experience from working within a radiology department.

In an attempt to aid in the development of the role of medical physicists working in the field of informatics, we have focused on areas that may be new to physicists in clinical departments. Arguably, the greatest difference between the physicist and the informaticist is in their expertise of computer science. Although familiarity with computers is necessary for a physicist, an informaticist must possess a far greater knowledge than a clinical physicist, knowing how to program computers and possessing an awareness and understanding of IT terminology, the operating systems available, and especially the ways systems interoperate. Interestingly, this difference between informaticists and physicists has diminished somewhat because younger physicists typically use computer modeling or digital image analysis in their graduate research. Knowing how to program a computer is not only useful for data mining but also essential in evaluating clinical information systems for potential weaknesses, failure modes, and areas requiring constant maintenance. Just as physicists work with technologists to ensure good image quality using equipment calibration and proper techniques, they can also work with PACS and radiology information system (RIS) administrators to ensure adherence to good data quality principles as well as to oversee monitor calibration, system performance, and system stability. The physicist can also use these clinical data to help drive quality improvement initiatives. Most importantly, the physicist often has a better appreciation of the clinical context in which the information is used than does the informaticist who lacks clinical knowledge.

The roles of diagnostic physicists in clinical operations and imaging informaticists overlap considerably, and few sites are large enough to justify a full time imaging informaticist. An interested physicist with appropriate expertise could take on the task of providing informatics leadership having developed an understanding of the additional areas of responsibility of informaticists.

III. INFORMATICS IN RADIATION THERAPY

The use of informatics in radiation therapy arose in response to three major issues encountered in the radiation oncology clinic.

The first issue was related to quality assurance needs, in particular, the need to record and verify the delivery of radiation treatment.[6–12] Early record and verify systems were designed to simply confirm radiation therapy machine parameters that had been manually set and validate the consistency of these parameters. If treatment was terminated unexpectedly, these systems could store data relevant to partial treatment received, thus enabling therapists to resume and complete the interrupted treatment. However, with the advent of complex computer-driven accelerators that supported capabilities, such as multiple beam energies, multileaf collimators, and dynamic wedges, the need arose for computer-based verification of treatment parameters.[13,14]

A 1999 report from the Institute of Medicine concerning medical errors[15] made both the medical community and the general public more aware of the possible occurrence of medical errors. Consequently, the development of record and verify systems and their increased use in radiation oncology have helped reduce the possibility and occurrence of medical errors.[16] These errors are potentially controllable and should be differentiated from uncertainties, which are inherent in the radiation therapy process so as to be quantified.[17] The transfer of data directly from a systematized radiation treatment plan to a record and verify system can be used to program linear accelerators more accurately. This has the potential to reduce the frequency of errors in the delivery of radiation.[18,19]

The second issue addressed by information systems was the introduction of the electronic medical record (EMR) in radiation oncology.[20] EMR initiatives began in the late 1980s and were principally led by efforts at the University of North Carolina.[21] Early radiation oncology EMRs were text-based systems storing patient-specific treatment information in a commercially available relational database.[22] As the database expanded, the record and verify system of information could be included in the EMRs. Just as a distinction often exists between the hard copies of hospital medical records and radiation oncology records, a distinction often exists between the hospital EMRs and radiation oncology EMRs.

The third issue was the handling and displaying of diagnostic images generated in radiation oncology. The radiotherapy picture archival and communication system (RT-PACS) was developed in the early 1990s as an outgrowth of the concurrent development of the radiology PACS.[23–25] Early in the development of the RT-PACS, researchers recognized the existence of functional differences between the RT-PACS and the conventional radiology PACS.[26] For example, the high resolution required for the identification of pathologic abnormalities using the radiology PACS was not required for the RT-PACS, as the pathologies had already been identified in the radiology images. On the other hand, the appearance of geometric distortions on images may have been acceptable using the radiology PACS but was not acceptable using the RT-PACS. This was because the images were used to plan radiation treatment using the latter. Clinicians originally used the RT-PACS primarily to support the comparison of simulator and portal images,[27] but others have combined the RT-PACS with information and treatment planning systems and have interfaced it with record and verify systems.[28,29]

In recent years, the delivery of radiation treatment has become more complex, incorporating the dynamic motion of multileaf collimators to deliver intensity-modulated treatment. In the future, tumor tracking during radiation treatment using complex dynamic multileaf collimator motions or combinations of gantry and table motions may be possible. Regardless of how the dynamic delivery of radiation is achieved, more elaborate record and verify systems will be required to support such capabilities. In addition, the extensive use of EMRs is likely in the future, including the development of searchable EMRs and software programs that can mine the data available in EMRs, and aid the analysis and correlation of patient data. Finally, as images play even greater roles in radiation oncology, the capabilities of the RT-PACS must expand to support images produced outside of radiation oncology. The most likely development will be to enable the RT-PACS to access hospital imaging PACSs, allowing radiation oncologists direct and full use of all imaging information in tumor targeting.

IV. CLINICAL STANDARDS IN DIAGNOSTIC IMAGING AND RADIATION THERAPY

Moving information from one computer system to another requires significant understanding of the systems involved; specifically, how to communicate and what the communicated information means. Standards and conventions for communicating information have been agreed on in order to improve safety, represent data consistently, and lower the cost of integration. For example, interoperability enables smoother information flow in a department and can reduce errors typically seen in clinical operations, such as the incorrect entry of patient demographics (e.g., medical record number). Using interoperable systems, the patient and examination can be selected from a modality work list with automatic entry of demographic information. This not only saves technologists time but also increases data integrity.

The main health care communication standards currently used throughout the world for medical images are the Digital Imaging and Communications in Medicine (DICOM) and health level 7(HL7). DICOM is the common language of medical imaging, covering diagnostic radiology as well as radiation therapy. The DICOM standard originated from the American College of Radiology/National Electrical Manufacturers Association; versions 1.0 and 2.0 were introduced in 1983 and 1988, respectively; the DICOM 3.0 standard was approved in 1993.[30] The Task Force on Digital Image Exchange introduced in 1978 by AAPM's Science Council released, in their AAPM Report 10, a standard format for digital image exchange from magnetic tapes based upon a flexible format concept of key-value variable pairs.[31] This model formed the basis for the underlying data structure within DICOM. While to date, the AAPM has had no formal relationship with DICOM, many physicists have played extensive roles in the development of many of the standards, such as the DICOM Grayscale Display Function Standards as well as Information Objects Definitions (IODs) for nuclear medicine images and radiation therapy.

DICOM's binary file format minimizes the storage and communication costs associated with large image matrices. Each data element is stored as a variable length key pair of the identifying code for the data element and its value. The image is stored as just another data element in the file. In the DICOM standard, data elements are assigned to information modules, such as the patient identification module. Each DICOM object, known as an IOD, is composed of many modules. This allows general modules to be common among several DICOM objects.

DICOM also defines a communication "transfer syntax" for transmitting DICOM objects. The syntax negotiates between sending and receiving systems; ensuring that the receiver supports the objects that the sender wants to send and that the two systems agree upon the method of transport. A service object pair, or SOP class, is a combination of a DICOM information object with a service class. A good example is the CT image storage SOP class, which defines how a system should send a CT image as a service class user (SCU) or receive a CT image as a service class provider (SCP). When purchasing a CT scanner a customer should ask for a vendor to support the DICOM CT Image Storage SOP class as a SCU. And similarly they should ask a PACS vendor to support the DICOM CT Image Storage SOP class as a SCP. DICOM has specified the format in which vendors should publish their interoperability capabilities in DICOM in a DICOM conformance statement.

DICOM also supports nonimage information objects, such as queries of a DICOM database, modality work lists, storage commitments, and modality performed procedure steps. These objects are used to ensure clean workflows and avoid the data integrity problems involved with transcription.

More recently, an extension of DICOM to include objects associated with radiation treatment plans has been developed. This extension, DICOM-RT, also includes objects such as structure sets (anatomic information), plans (beams and their configurations), dose distributions, and radiation treatment records to be communicated along with images.

HL7 is a standard code of information interchange, fixed delimiter, transactional broadcast standard for the communication of medical information, such as admissions, discharges, transfers, orders, and final reports. HL7 is used for HIS communications, namely, the master patient index, EMR, and physician order entry.

A further challenge concerning "clinical" standards "in diagnostic imaging and radiation therapy" is the relatively long adoption period by vendors, which can be 5-10 years. The Integrating the Healthcare Enterprise (IHE) initiative seeks to accelerate this adoption through vendor participation and public demonstrations. The IHE also attempts to set conventions on existing standards to enable functional integration.[32] As DICOM did in the past, the IHE initiative strives to increase the integration of health care information systems (e.g., RIS, PACS, and EMR) with the aim of unifying information stored by multiple organizations, thus providing radiologists with more informed views of a patients' entire medical records.[32]

An example is the radiology "scheduled workflow integration profile," which incorporates four DICOM objects and five HL7 messages to accomplish effective transfer among the RIS, the PACSs, and imaging modalities. The IHE initiative is useful for strategic planning as it helps in setting a vision for integration and bundles open standards to help achieve better clinical integration by using a reduced-cost model for proprietary integration.

V. PATIENT DATA PROTECTION

As an old physics joke goes "300 000 km per second is not only a good idea, it's the law." Similarly, treating patient records as private documents that must be protected, is also no longer just a good idea but the law. In the United States, two forms of interpersonal communication have come to be protected under the law: Attorney-client privilege and doctor-patient exchanges. However, what used to be inferred as protection against discovery in a judicial proceeding has now come to mean broader protection against intrusion by any nonessential third parties.

The most recent and cogently stated collection of these principles under the law is the Health Insurance Portability and Accountability Act (HIPAA) legislation.[33] In addition to its primary purpose of assuring that a patient's medical rights are not detrimentally affected when changing jobs, passage of HIPAA resulted in the development of an important detailed clause concerned with patient privacy. Known as the Privacy Rule, the general intent of this clause was to highlight the rights of patients by ensuring access to their records, controlling the information third parties can access, and compelling providers to protect personal information from being tampered with HIPAA. It was also designed to prevent the loss or unauthorized disclosure of information to unauthorized third parties. A simple remedy to assure this is maintaining audit trails of all who have access to personal medical records.

HIPAA became law in 1996 and its enforcement is entrusted to the U.S. Department of Health and Human Services.[34] However, enforcement of the Privacy Rule was deferred until April 2003 to permit providers sufficient time to comply with regulations. From halfway through 2006, 14 000 out of a total of 19 000 complaints have been closed without fines, with the remaining complaints pending response from the nonconforming site.[35] To date, the philosophy of enforcement has been to encourage compliance and force violators to comply, rather than to impose punitive fines.

Numerous concerns related to establishing and maintaining HIPAA compliance have been voiced. An American College of Radiology guideline, co-authored by radiologists, physicists, and IT experts, describes some basic strategies for covering both the business and technical aspects of HIPAA.[36] Many institutions have a HIPAA officer who interprets and enforces HIPAA policies and procedures. Among other duties, such officers should develop policies for disclosure, access, accounting, amendments, business associate agreements, verification, and complaints. They are often charged with developing training programs and technical infrastructure concerning software and hardware policies to ensure compliance.

The Society of Imaging Informatics in Medicine (SIIM) published a guidebook describing some of the technical methods used to secure electronic data.[37]

The U.S. Department of Health and Human Services has taken a gentle approach to its HIPAA enforcement strategies. However, recent events, such as the theft of laptops containing patient records from the U.S. Department of Veterans Affairs, are likely to lead to greater public pressure for the strict enforcement of HIPAA.[38] Furthermore, computer malware—viruses and worms—have become more organized, dangerous, and profit driven.[39] The need for greater vigilance will increase over time, and, in turn, health care concerns will come under greater focus for both individuals and the government.

As health care providers, medical physicists are obliged to ensure patient care positions and are, therefore, charged with ensuring and maintaining patient confidentiality at all times, especially when related to the use of technology. Medical physicists have an ethical as well as legal responsibility to assure that all information systems in their departments, whether diagnostic or therapeutic and in use or planned, are HIPAA compliant. One particular source of HIPAA violations occurs frequently when patient data are presented as part of a research study. Medical data used in a research study, as opposed to data used in the care of a specific patient, should be anonymous and kept separate from clinical data. Ideally, medical information systems that handle patient data should have anonymizing mechanisms that remove patient identifying information when data are transferred into a research study. A potential way for medical physicists to assure this for new equipment purchases is to, in cooperation with the HIPAA enforcement officer, develop acceptance tests that enforce at a minimum: (a) Individual user log ins, (b) screen blanking after a configurable number of minutes of inactivity, and (c) evidence of user audit logs and other such items as may jointly occur to the physicist and HIPAA officer.

VI. INTEGRATED PACS AND HIS

Who won the game? It is a simple question but impossible to answer unless the two parties in the conversation know the sport and date and location of the contest. Similarly, radiologists prefer not to offer a patient a diagnosis using a single imaging exam if they can gain access to other relevant contextual data. The integration of the PACS with other clinical data systems is a key feature in this context.

In its infancy during 1993, PACSs information systems, operational in health care centers, were largely considered to be information islands. To obtain a global view of the patient's laboratory test, pathologic, surgery, and other results, providers often had to log on separately in four or more information systems. Patient data were not synchronized, as users had to exercise care to ensure that they were looking at the results for the same patient in all of the applications.

FIG. 2. A PACS console with an RIS-driven work list typically found in many hospitals today.

In the late 1990s, individual departments began sharing their results under a common umbrella system, the HIS, or more generically, the EMR. Having an amalgamated system of information sharing, presented advantages when accessing patient test results. In addition, the chance of mistaking or comparing the results of different patients was eliminated. The HIS enabled centralized data retrieval and effectively supported decision-making procedures. The development of the EMR was a significant breakthrough for radiologists in that it permitted global viewing of patient histories, leading to more informed diagnoses.

Despite their benefit, EMRs had yet to be integrated with other data systems to achieve an optimum effect in the 1990s. Radiology departments often had a RIS in addition to a PACS, though synchronization of the EMR, RIS, and PACS was rare. Users still had to manually maintain and monitor patient data using at least two if not all three of these systems.

In 2003, RIS and PACS vendors began to realize that using a RIS to drive a PACS was logical as well as beneficial. This would involve HIS sending an order to the RIS before the PACS ever knows about it. The RIS then forwards the order to the PACS. By using the RIS to build work lists that drive the PACS, the resulting work lists can use many more parameters to improve work list granularity and show reports on priors, all without the risk of sending redundant copies to the PACS and showing other information that the PACS does not have in its database, such as the identity of the ordering physician (Fig. 2).

It is becoming common practice for radiologists to perform a single sign-on that loads the RIS, an interpretation work list, a PACS exam synchronized to the patient context work list, and an EMR instance that is also synchronized to the interpretation work list. With complete uninterrupted access to all relevant images, reports, and care details from other departments, the radiologist is in a much better position to make a comparative diagnosis based on technically accurate information.

With the addition of a synchronized speech-recognition application, the health care provider is now in a position to provide more accurate reports, which, along with their images, are available to the clinician viewing the EMR; all within minutes after the patient undergoes imaging.

The scenario outlined above describes a base platform that makes multiple technologies available to the next generation of radiologists. An example of such technology is testing for appropriateness criteria from which it can be ascertained whether an ordered examination is consistent with the patient's presentation and past findings. The advantage of such a system is the avoidance of expensive procedures, which hitherto may not have been necessary or have been reimbursed. In addition, such a platform can be expanded to include decision support tools; namely, computer-aided detection to carefully scrutinize medical details and suggest differential diagnoses and further useful tests. Finally, new IHE profiles will expand this platform further, even if data inputs are acquired from different health care facilities using different patient and examination identifiers.[40]

Medical Physicists can increase their effectiveness and value by becoming conversant in these issues and guiding purchases of new equipment accordingly.

VII. TELEMEDICINE AND TELECARE

The subject of telemedicine–the delivery of medicine at a distance–is a very broad subject that is far beyond the scope of this article. To limit the scope, we have replaced the word telemedicine with the term telemedical physics, which is the performance of medical physics or medical physics-related procedures at a distance. Some of the telemedical physics applications are relatively obvious, such as the direct review of radiologic images using a remote workstation.[41,42] This application of telemedical physics is readily accomplished with the use of PACSs, which is addressed elsewhere in this article.

Other applications of telemedical physics are not so obvious however. For example, telemedical physics can play a major role in small regional health care facilities that do not have the equipment or staffing resources found in large centers. In addition, satellite clinics working in cooperation with major medical centers can have real-time access to much of the expertise available at a central facility. An example of this access is the use of teleconferencing to facilitate chart rounds, quality assurance conferences, and routine meetings resulting in minimal inconvenience to the participants.[43,44]

Such communications require relatively extensive networking capabilities. However, telemedical physics has been in existence and practiced long before the use of computer-based communication had become widespread. An example of "medical physics at a distance" and practiced for many years is remote dosimetry. Because thermoluminescent dosimetry (TLD) materials are capable of storing dosimetric information for relatively long periods of time and can withstand handling by parcel delivery services, they have been the dosimetric materials of choice for remote dosimetry systems. In most remote dosimetry systems, the thermoluminescent dosimeters are mailed to the remote site along with instructions to irradiate them to specified doses. The dosimeters are then returned to the service provider where the doses are read out. The accuracy rate of TLD at those institutions experienced in using it is better than 1%. Remote TLD has been in use for many years by the Radiological Physics Center (RPC) to ensure dosimetric consistency among institutions involved in clinical trials in radiation oncology. In addition, several institutions perform fee-for-service remote dosimetry. This enables physicists to verify the accuracy of their dosimetry when ion chamber intercomparisons are not feasible. It also provides the capability of *in vivo* patient dosimetry in institutions that do not have in-house TLD systems.

Remote radiation treatment planning is another application of telemedical physics that has been in practice for many years. A radiation oncology clinic that does not have treatment-planning computers can send patient contours to a central planning site, for example, a large radiation oncology center, where plans can be developed and sent to the clinic. In previous years, such information was transferred via mail, messenger, or fax. However, this information can now be sent via direct computer communications.

Olsen *et al.*[44] identified three levels of service that must be established to provide telemedicine. They based these levels on the nature of data transfer between central facilities and remote sites: Level I, the transfer of alphanumeric information in addition to teleconferencing; Level II, the transfer of images to and from a database, including operating on specific images after they have been transferred from the database; Level III, real-time operations using images from remote workstations. The major issue that must be addressed when using the various levels of service is that of bandwidth, which clearly increases as the level of service progresses.

An important component of radiation treatment planning in which telemedical physics capabilities can be used to great advantage is the delineation of target volumes and normal anatomic structures.[45] Programmers have developed groupware that enables collaboration among participants in the planning process, including the review of multimodality medical images and the delineation of target volumes. Whereas scheduling multiple experts to view images and contours at a single location may be difficult, the ability to display information at multiple sites using such groupware can alleviate this very serious problem and allow for collaborations that may otherwise be unachievable.

In principle, some medical physics quality assurance activities may be performed remotely, whereas some may require on-site intervention. For example, one might conceive of a system that uses electronic portal imaging devices (EPIDs) as part of a quality assurance program. Another possibility is the use of an EPID to measure the exit fluence of radiation from an incident intensity-modulated radiation field (on a test phantom) as a means of performing intensity-modulated radiation therapy quality assurance. Finally, EPID images may be acquired on-site by a technologist and reviewed off-site by a medical physicist.

VIII. WHAT IS THE RELATIONSHIP BETWEEN AAPM AND INFORMATICS UP TO THE PRESENT, AND WHAT POSITIVE ACTIONS SHOULD BE PROPOSED?

The medical informatics topics described herein relate to an academic discipline defined in 1990 by Greenes and Shortliffe[46] as "the field that concerns itself with the cognitive, information processing, and communication tasks of medical practice, education, and research, including the information science and the technology to support these tasks." In that same year, Shortliffe *et al.*[1] edited the first textbook on medical informatics, which is now in its third edition.[5] The field of medical informatics is now a recognized area of study at many universities and medical centers.

As a professional society, the AAPM has been relatively slow to embrace this emerging discipline. Although several topics in medical informatics are discussed at annual AAPM meetings, many members interested in radiologic informatics have chosen to work closely with other societies, such as the SIIM. Notably, since 2000, three active AAPM members have chaired the SIIM. The physical processes in medicine as they pertain to diagnostic imaging and cancer treatment, particularly ionizing and nonionizing radiation processes, continue to dominate the clinical, education, and research activities of the AAPM. The methods of medical physics are increasingly related to informatics in health care. For example, diagnostic imaging studies are ordered in relation to outcomes, protocols are established in relation to history, and images are indexed for teaching purposes. In radiation oncology, treatment plans are optimized by rapid access to patient information while treatment verification is managed using databases Outcomes are assessed by immediate access to national trials data. To improve the skills of medical physicists, training programs and curricula must include core concepts in medical informatics and an increased emphasis on computer system and database management skills. Similarly, opportunities for continuing education must be developed to help medical physicists currently in practice.

In recognition of this trend, the AAPM Science Council, as part of its reorganization, established the Imaging Informatics Subcommittee (IISC) in November 2004 (http://www.aapm.org/org/structure/?committee_code=IISC). Additionally, the theme of the 1999 AAPM summer school was "Practical Digital Imaging and PACS," for which occasion Seibert *et al.*[47] edited a monograph. The current short-range initiatives of this subcommittee include active participation in the DICOM standards committee and the development of teaching curricula and internet resources for continuing education. Furthermore, as part of the annual AAPM meeting, a set of continuing education lectures on imaging informatics is now offered. It is felt that similar efforts in radiation oncology are long overdue.

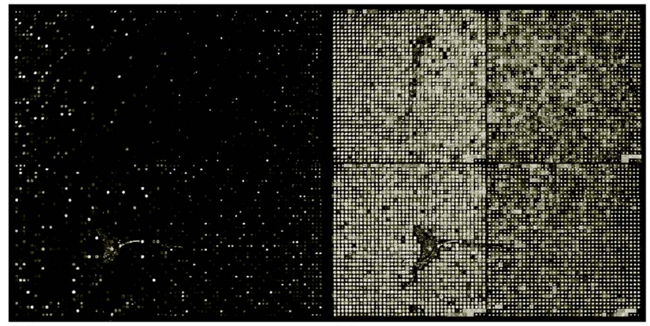

FIG. 3. Example of (a) an original microarray image and (b) a restored microarray image obtained using a spot-adjustable robust framework of image processing and analysis techniques (Ref. 49).

Medical informatics is quite likely to develop into a major subspecialty of medical physics. This can be achieved in part with a focus by scientific medical physics-related journals on the highly technical nature of information processing in medicine.

IX. CONCLUSION

For more than a century, physicists have cooperated with health professionals and contributed to the diagnosis and treatment of various diseases. Medical physics has evolved in an attempt to meet the increasing needs in the medical profession more effectively. Scientists trained in this specialty have worked in association with radiologists for decades; and their contributions have been crucial, especially concerning the appropriate use of x rays and computed tomography scans. Furthermore, in recent years there has been an increased reliance on medical physicists in meeting diagnosis needs and the treatment of diseases. Consequently, the role of medical physicists is now more demanding than ever and has taken on an exploratory nature. An example of the new challenges is the use of microarrays[48] (Fig. 3).[49] In this respect, medical physicists have recently been actively engaged in the development of IT systems.

Medical physicists must gain expertise in the field of medical informatics and, in so doing, rise to the challenge of taking responsibility by engaging in corporate management decisions and the dissemination of information needed by other health professionals. This is a prerequisite for the effective management of hospital systems in which highly trained medical physicists can play a predominant role.[3,50] The prospect of medical physicists assuming such responsibilities is appealing to many health care providers, given that the field is struggling with seemingly insurmountable financial problems and maintenance of quality service.[51]

In the not-too-distant future, the essential features of informatics must be focused on for the clinical implementation of different informatics features in health care. For example, all new imaging devices should conform to DICOM standards and be interconnected in HISs. Also, archival imaging systems must evolve and be equipped with larger and faster databases. Services to patients will drive changes that will impact health care in general. Web-based applications will assist in this role given that continuous critical parameter monitoring is of paramount importance for appropriate follow-up of specific diseases.[52]

To meet future informatics needs, three major features of medical physics, namely, research, education, and clinical service should be further developed. These have previously been discussed by Hendee and Mower.[53] Research has already led to major advances in enhancing both the diagnosis and treatment of different diseases. Molecular imaging and biologic conformal radiation therapy are current subjects of cutting-edge research. With regard to education, specialists should seek to raise standards, while at the same time, provide specific educational and training programs in the field of informatics. The role of medical physics has been established in the field of clinical service for about 100 years. Cooperation between physicists and radiologists or radiation oncologists in both radiation-based diagnosis and treatment is now standard practice.

As the demands on medical physicists increase, more opportunities for their evolution will arise. Medical physicists should be ready to meet these demands by offering premium scientific input and, in so doing, standardize their role in health care. The ability to take part in the informatics-related health care fields discussed above undoubtedly requires a high level of education and understanding in those areas. Such an ability would enhance the role of medical physicists as knowledge facilitators, which would clearly promote the importance of medical physicists in health care throughout the world.

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[1]E. H. Shortliffe, L. Perreault, G. Wiederhold, and L. M. Fagan, *Medical Informatics: Computer Applications in Health Care* (Addison-Wesley, Reading, Massachusetts, 1990).
[2]P. G. Nagy, "The future of PACS," Med. Phys. **34**, 2676–2682 (2007).
[3]G. C. Nikiforidis, G. C. Kagadis, and C. G. Orton, "Point/Counterpoint. It is important that medical physicists be involved in the development and implementation of integrated hospital information systems," Med. Phys. **33**, 4455–4458 (2006).
[4]J. H. Trueblood and K. R. Hogstrom, "Medical physicists should position themselves as institutional resources in expanding areas such as healthcare informatics and information networking," Med. Phys. **27**, 631–633 (2000).
[5]E. H. Shortliffe and J. J. Cimino, *Biomedical Informatics: Computer Applications in Health Care and Biomedicine*, 3rd ed. (Springer, New York, 2006).
[6]J. Cederlung, R.-O. Lofroth, and S. Zetterlund, "An attempt to check radiation treatment parameters with a mini-computer," in *Computer Applications in Radiation Oncology, Proceedings of the Fifth International Conference on the Use of Computers in Radiation Therapy*, edited by E. S. Sternick (University Press of New England, Hanover, New Hampshire, 1976), pp. 60–62.
[7]A. Chung-Bin, P. Kartha, T. Wachtor, and F. Hendrickson, "Development and experience in computer monitoring and verification of daily patient treatment parameters," in *Computer Applications in Radiation Oncology, Proceedings of the Fifth International Conference on the Use of Computers in Radiation Therapy*, edited by E. S. Sternick (University Press of New England, Hanover, New Hampshire, 1976), pp. 57–59.
[8]P. Dickof, P. Morris, and D. Getz, "Vrx: a verify-record system for radiotherapy," Med. Phys. **11**, 525–527 (1984).
[9]D. H. Fredrickson, C. J. Karzmark, D. C. Rust, and M. Tuschman, "Experience with computer monitoring, verification and record keeping in radiotherapy procedures using a Clinac-4," Int. J. Radiat. Oncol. Biol. Phys. **5**, 415–418 (1979).
[10]D. Kipping and R. Potenza, "The CART system: Automated verification, recording, and controlled accelerator setup," in *Computer Applications in Radiation Oncology, Proceedings of the Fifth International Conference on the Use of Computers in Radiation Therapy*, edited by E. S. Sternick (University Press of New England, Hanover, New Hampshire, 1976), pp. 63–75.
[11]R. Mohan, K. C. Podmaniczky, R. Caley, A. Lapidus, and J. S. Laughlin, "A computerized record and verify system for radiation treatments," Int. J. Radiat. Oncol. Biol. Phys. **10**, 1975–1985 (1984).
[12]M. E. Rosenbloom, L. J. Killick, and R. E. Bentley, "Verification and recording of radiotherapy treatments using a small computer," Br. J. Radiol. **50**, 637–644 (1977).
[13]W. W. Seelentag, U. M. Lutolf, and R. Heinze-Assmann, "Dynaver for treatment verification and recording," in *The Use of Computers in Radiation Therapy, Proceedings of the Ninth International Conference on the Use of Computers in Radiation Therapy*, edited by I. A. D. Bruinvis *et al.* (North-Holland, Amsterdam, 1987), pp. 379–382.
[14]T. Takahashi, K. Sakamoto, and A. Kikuchi, "Computer controlled verification of irradiation condition and its recording in multiple irradiation apparatuses," in *Proceedings of the Ninth International Conference on the Use of Computers in Radiation Therapy*, edited by I. A. D. Bruinvis *et al.* (North-Holland, Amsterdam, 1987), pp. 383–385.
[15]L. T. Kohn, J. M. Corrigan, and M. S. Donaldson, *To Err Is Human: Building a Safer Health System* (National Academy Press, Washington, DC, 1999).
[16]D. W. Bates, M. Cohen, L. L. Leape, J. M. Overhage, M. M. Shabot, and T. Sheridan, "Reducing the frequency of errors in medicine using information technology," J. Am. Med. Inform. Assoc. **8**, 299–308 (2001).
[17]G. A. Patton, D. K. Gaffney, and J. H. Moeller, "Facilitation of radiotherapeutic error by computerized record and verify systems," Int. J. Radiat. Oncol. Biol. Phys. **56**, 50–57 (2003).
[18]E. E. Klein, R. E. Drzymala, J. A. Purdy, and J. Michalski, "Errors in radiation oncology: a study in pathways and dosimetric impact," J. Appl. Clin. Med. Phys. **6**, 81–94 (2005).
[19]T. K. Yeung, K. Bortolotto, S. Cosby, M. Hoar, and E. Lederer, "Quality assurance in radiotherapy: Evaluation of errors and incidents recorded over a 10 year period," Radiother. Oncol. **74**, 283–291 (2005).
[20]S. L. Sailer, J. E. Tepper, L. Margolese-Malin, J. G. Rosenman, and E. L. Chaney, "RAPID: An electronic medical records system for radiation oncology," Semin. Radiat. Oncol. **7**, 4–10 (1997).
[21]S. A. Salenius, L. Margolese-Malin, J. E. Tepper, J. Rosenman, M. Varia, and L. Hodge, "An electronic medical record system with direct data-entry and research capabilities," Int. J. Radiat. Oncol. Biol. Phys. **24**, 369–376 (1992).
[22]H. Gfirtner, F. Kropf, and G. Schenk, "A check and recording system based on the relational data base Sybase realized on NeXT workstations," in *Proceedings of the Eleventh International Conference on the USE of Computers in Radiation Therapy*, edited by A. R. Hounsell, J. M. Wilkinson, and P. C. Williams (North-Holland, Amsterdam, 1994), pp. 84–85.
[23]K. P. McGee, I. J. Das, D. A. Fein, E. E. Martin, T. E. Schultheiss, and G. E. Hanks, "Picture archiving and communications systems in radiation oncology (PACSRO): Tools for a physician-based digital image review system," Radiother. Oncol. **34**, 54–62 (1995).
[24]G. Starkschall, "Design specifications for a radiation oncology picture archival and communication system," Semin. Radiat. Oncol. **7**, 21–30 (1997).
[25]E. Takenaka and R. Hosaka, "Radiation therapy PACS," in *The use of Computers in Radiation Therapy, Proceedings of the Ninth International Conference on the Use of Computers in Radiation Therapy*, edited by I. A. D. Bruinvis, P. H. van der Giessen, H. J. van Kleffens *et al.* (North-Holland, Amsterdam, 1987), pp. 213–217.
[26]M. Y. Law and H. K. Huang, "Concept of a PACS and imaging informatics-based server for radiation therapy," Comput. Med. Imaging Graph. **27**, 1–9 (2003).
[27]G. Starkschall, S. W. Bujnowski, N. W. Wong, X. J. Li, L. Dong, A. L. Boyer, and K. R. Hogstrom, "Implementation of image comparison methods in a radiotherapy PACS," in *Proceedings of the Eleventh International Conference on the Use of Computers in Radiation Therapy*, edited by A. R. Hounsell, J. M. Wilkinson, and P. C. Williams (North-Holland, Amsterdam, 1994), pp. 186–187.

[28]G. Becker, A. Mack, R. Jany, J. Major, and M. Bamberg, "PACS and networking systems in radiotherapy," in *Proceedings of the Eleventh International Conference on the Use of Computers in Radiation Therapy*, edited by A. R. Hounsell, J. M. Wilkinson, and P. C. Williams (North-Holland, Amsterdam, 1994), pp. 46–47.
[29]S. Hyodynmaa, J. Aalto, and M. Pitkanen, "A computer network for transferring radiotherapy images and treatment set-up data," in *Proceedings of the Eleventh International Conference on the Use of Computers in Radiation Therapy*, edited by A. R. Hounsell, J. M. Wilkinson, and P. C. Williams (North-Holland, Amsterdam, 1994), pp. 54–55.
[30]DICOM Web site, http://medical.nema.org accessed August 1, 2007.
[31]B. S. Baxter, L. E. Hitchner, and G. Q. J. Maguire, "A standard format for digital image exchange," AAPM Report No. 10, 1982.
[32]IHE, IHE Web page, http://www.ihe.net/Technical_Framework/ accessed August 1, 2007.
[33]HHS-Office for Civil Rights–HIPPA, http://www.hhs.gov/ocr/hipaa/ accessed August 28, 2007.
[34]United States Department of Health and Human Services, http://www.hhs.gov accessed August 29, 2007.
[35]Medical privacy law nets no fines, http://www.washingtonpost.com/wp-dyn/content/article/2006/06/04/AR2006060400672.html, accessed August 29, 2007.
[36]ACR, Practice Guideline for Electronic Medical Information Privacy and Security, 2004, Res. 12, available at http://www.acr.org/SecondaryMainMenuCategories/quality_safety/guidelines/med_phys/electronic_medical_info.aspx.
[37]S. J. Dwyer, B. I. Reiner, and E. L. Siegel, *SIIM U Primer 5: Security Issues in the Digital Medical Enterprise*, 2nd ed. (Society for Computer Applications in Radiology, 2004).
[38]Veterans Administration, U.S. Says Personal Data on Millions of Veterans Stolen, http://www.washingtonpost.com/wp-dyn/content/article/2006/05/22/AR2006052200690.html, accessed August 1, 2007.
[39]C. A. Schiller and J. Binkley, *Botnets: the Killer Web App* (Andrew Williams, Syngress Publishing Inc., 2007).
[40]I. RHIO, Technical Requirements for Participation in the Cross-Enterprise Document Sharing Component of the HIMSS 2006 Interoperability Showcase, http://www.himss.org/Content/files/IHE_participation_req.pdf.
[41]T. L. Ebbert, C. Meghea, S. Iturbe, H. P. Forman, M. Bhargavan, and J. H. Sunshine, "The state of teleradiology in 2003 and changes since 1999," AJR Am. J. Roentgenol. **188**, W103–W112 (2007).
[42]S. Hashimoto, H. Shirato, T. Nishioka, K. Kagei, S. Shimizu, K. Fujita, H. Ogasawara, Y. Watanabe, and K. Miyasaka, "Remote verification in radiotherapy using digitally reconstructed radiography (DRR) and portal images: A pilot study," Int. J. Radiat. Oncol. Biol. Phys. **50**, 579–585 (2001).
[43]H. T. Eich, R. P. Muller, A. Schneeweiss, K. Hansemann, R. Semrau, N. Willich, C. Rube, S. Sehlen, M. Hinkelbein, and V. Diehl, "Initiation of a teleradiotherapeutic network for patients in German lymphoma studies," Int. J. Radiat. Oncol. Biol. Phys. **58**, 805–808 (2004).
[44]D. R. Olsen, S. Bruland, and B. J. Davis, "Telemedicine in radiotherapy treatment planning: requirements and applications," Radiother. Oncol. **54**, 255–259 (2000).
[45]G. C. Sakellaropoulos, G. C. Kagadis, C. Karystianos, D. Karnabatidis, C. Constantoyannis, and G. C. Nikiforidis, "An experimental environment for the production, exchange and discussion of fused radiology images, for the management of patients with residual brain tumour disease," Med. Inform. Internet Med. **28**, 135–146 (2003).
[46]R. A. Greenes and E. H. Shortliffe, "Medical informatics. An emerging academic discipline and institutional priority," JAMA **263**, 1114–1120 (1990).
[47]J. A. Seibert, L. J. Filipow, and K. P. Andriole, *Practical Digital Imaging and PACS* (Medical Physics Publishing, Madison, Wisconsin, 1999).
[48]J. L. DeRisi, V. R. Iyer, and P. O. Brown, "Exploring the metabolic and genetic control of gene expression on a genomic scale," Science **278**, 680–686 (1997).
[49]A. Daskalakis, D. Cavouras, P. Bougioukos, S. Kostopoulos, D. Glotsos, I. Kalatzis, G. C. Kagadis, C. Argyropoulos, and G. Nikiforidis, "Improving gene quantification by adjustable spot-image restoration," Bioinformatics **23**, 2265–2272 (2007).
[50]R. Haux, "Health information systems-past, present, future," Int. J. Med. Inform. **75**, 268–281 (2006).
[51]D. Blumenthal and J. P. Glaser, "Information technology comes to medicine," N. Engl. J. Med. **356**, 2527–2534 (2007).
[52]K. P. Andriole, in *Advances in Medical Physics 2006*, edited by A. B. Wolbarst, R. G. Zamenhof, and W. R. Hendee (Medical Physics Publishing, Madison, Wisconsin, 2006), pp. 201–227.
[53]W. R. Hendee and H. W. Mower, "A time of opportunity in the education of medical physicists: Report of a multi-organizational summit on the education of medical physicists," Med. Phys. **33**, 3327–3332 (2006).