Mobile Computing for Radiology

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The rapid advances in mobile computing technology have the potential to change the way radiology and medicine as a whole are practiced. Several mobile computing advances have not yet found application to the practice of radiology, while others have already been applied to radiology but are not in widespread clinical use. This review addresses several areas where radiology and medicine in general may benefit from adoption of the latest mobile computing technologies and speculates on potential future applications.

Key Words: Mobile computing; radiology.

The rapid changes in mobile computing hardware and software affect many aspects of our lives both personally and professionally. The rate at which technology has changed in recent years presents a particular challenge in medicine, where new ideas are typically accepted into clinical practice only after a comprehensive period of validation, to ensure that patients are helped and not harmed by the technology. These changes are particularly relevant to radiology, where our day-to-day workflow is intimately intertwined with the technological tools at our disposal. Several mobile computing advances have not yet found application to the practice of radiology, whereas others have already been applied to radiology but are not yet in widespread clinical use. Presented here are several areas where the advances in mobile computing have the potential to reshape the way we think of and practice not only radiology but medicine as a whole. Several trends in mobile technology are discussed, as well as their current and potential applications to radiology and medicine in general.

MOBILE COMPUTING: PAST THROUGH THE PRESENT

Mobile Computing: Its Evolution to the Present Day

Radiology makes significant use of the latest computers for each step in the pathway from image acquisition to reporting. Consequently, radiologists often unexpectedly find themselves leaders in the application of computers in medicine.

Frederick McKinley Jones invented the portable X-ray machine circa 1920 (1). Medicine had to wait until 1975 for the first commercially successful portable ultrasound unit, the ADR Model 2130 (Advanced Diagnostic Research), which could display only 16 shades of gray and used an oscilloscope for a display (2). Mobile computed tomography (CT) has been in existence for many years, and its applications have been evolving. In January 2012, Rhode Island Hospital was the first in the world to acquire a portable CT scanner specifically for use in operating rooms (3). “Mobile MRI [magnetic resonance imaging]” units on trailer trucks serve niche markets around the United States, but it will likely be some time before truly portable MR scanners can be wheeled around the hospital.

The pocket-sized calculator was not available until the 1970s. In the short time since then, we have seen the introduction of graphing calculators, Palm Pilots®, laptops, BlackBerry® devices, smartphones, touch screen smartphones, and tablet computers. Palm Pilots®, with their fingertip pharmacopoeias, were replaced by smartphones, which offered the advantage of more versatile and colorful interfaces, intrinsic connectivity, and ubiquity. Tablet computers represent a hybrid of the smartphones and laptop computers and in many instances are preferred to traditional paperbound textbooks and journal articles. Mobile radiology image interpretation has only recently become approved, with the diagnostic radiology application for mobile devices receiving Food and Drug Administration clearance on February 4, 2011 (4).

Current Image Display Capabilities

The American College of Radiology (ACR)/American Association of Physicists in Medicine (AAPM)/Society for Imaging Informatics in Medicine (SIIM) Technical Standard for Electronic Practice of Medical Imaging (5) provides useful benchmarks to guide the evaluation of currently available mobile platforms. Current smartphones and tablet computers

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TABLE 1. Mobile Computing Display Performance

Monitor	Cost	OS	Resolution	PLW	Black Level	CNR LAL	CNR HAL	Reflectivity
Barco Coronis Fusion 10 MP	\$32,000	N/A	4096 × 2560	500–1250		950		
iPad	\$499	iOS	2048 × 1536	421	0.48	877	55	7.7%
Samsung Galaxy Tab 10.1″	\$350	Android	1280 × 800	464	0.51	916	57	8.2%
Microsoft Surface RT	\$499	Windows 8	1366 × 768	428	0.39	1097	74	5.8%
ACR standards				~350	1			

Cost, approximate cost; OS, operating system; PLW, peak luminance for white (in cd/m^2); black level, given in cd/m^2; CNR LAL, contrast-to-noise ratio in low ambient light; CNR HAL, contrast-to-noise ratio in high ambient light; reflectivity, screen reflectivity; ACR dtandards, ACR standards for displays used for official interpretation of images other than mammography.

have sufficient processor speed, storage capability, and working memory for viewing many diagnostic image data sets. Mobile computer display has seen significant advances in recent years. Table 1, summarized from data available online (6), compares display characteristics of some of the more popular devices on the market currently with ACR recommendations and conventional diagnostic radiology monitors. Krupinski et al (7) give a more thorough description of the properties of diagnostic imaging monitors.

Wireless Data Transfer

Mobile devices have increasingly faster broadband Internet connections, which facilitate the transfer of large imaging data sets. The average speed of wireless networks has increased at a rate similar to hardwired networks. Current devices on the fastest LTE broadband networks have speeds that range from 10 to 50 Mbps (about as fast as a wired home connection in 2008), compared with wired home Internet connection speeds in the range of 100 to 500 Mbps. Such wireless transmission speeds make mobile devices a more viable option for use in radiology and medicine.

New Mobile Devices and Their Potential Application to Medicine and Imaging

The technical capabilities of current mobile devices and wireless networks are well within the requirements of many radiology applications. As hardware and display technologies continue to improve, mobile devices may find uses that expand the current paradigm of diagnostic medical imaging. Many potential applications are discussed later.

APPLICATIONS FOR REFERRING PHYSICIANS

Mobile Computing for Clinicians

Many health care systems have or are making the switch to electronic medical records (EMRs) for greater ease of data storage and revival. The Department of Veterans Affairs made the switch to digital years ago, allowing health care providers at more than 1400 facilities to share a patient's history as well as digital images of the patient's past radiologic imaging and laboratory results (8). The new challenge is to make these data available to clinicians on a mobile platform. The benefits of enabling a secure mobile computing device platform provide several benefits for patient care. The mobile computing device has become the interface to many different types of equipment, such as radiology stations, paper charting, nursing desktop computers, biotelemetry monitors, dictation stations, and prescription pads. Integrating mobile devices with EMRs is often successful in reducing costs and error rates (9).

The care provider can work on a single personalized mobile computer device and not have to be concerned with finding an open desktop computer or varied desktop environments. Health care professionals then have information pertaining to the imaging studies they will order or have ordered at their fingertips.

Computerized Physician Order Entry

Computerized physician order entry (CPOE) is a process that allows a physician to enter medical orders directly and to manage the results of these orders (10). CPOE systems are designed and implemented with the intent of simplifying and streamlining clinical workflow. CPOE may be integrated with evidence-based clinical decision support (CDS), assisting with appropriate selections of imaging studies (11,12). Information systems can also assist in the flow of care in a radiology department by making patient laboratory values and weight available or identifying patients for whom an order for intravenous contrast material may not be inappropriate. Such information integration has been shown to be associated with improved patient safety (13).

CPOE is already available for hardwired computer terminals. However, such tools are often not available when a physician is interacting with a patient. A CPOE tool available on a smartphone using a specialized application may facilitate physicians entering orders quickly and directly with less chance for errors (i.e., if the order is transcribed by physician support staff). It follows that such a portal could lend itself to a readily accessible mobilized platform, yielding a higher quality of care through improved patient histories and more appropriate exam protocol (14). Mobility is a central feature of health care delivery and clinical work, especially as physicians often work in multiple health care facilities (15–18).

Clinical Decision Support

Clinical decision support (CDS) typically refers to computerized evidence-based guidelines that assist the physician with patient management. For referring physicians, this can include warnings that appear on-screen when attempting to order a particular drug that is contraindicated in a certain patient population.

For the purpose of the interface between referring physicians and radiologists, CDS via mobile technology may provide imaging recommendations based on the ACR's Appropriateness Criteria (ACR-AC). The ACR-AC is a set of expert recommendations based on the current evidence-based imaging guidelines. For many common clinical scenarios, it details and grades the utility (from 0 to 9) of all available imaging modalities. It also takes into consideration their relative radiation levels, as well as exceptions to the standard protocols (such as pregnancy).

While the ACR-AC are available on the ACR's website at no cost, many referring physicians may not be able to consistently refer to the guidelines when ordering imaging studies. A more efficient option would be to have the ACR-AC and other CDS tools incorporated into a CPOE system. Such a system could bridge the gap between evidence-based guidelines for clinical diagnostics and imaging utilization. Clinical decisions for presumptive diagnostics often utilize evidence-based risk stratification systems, such as the Thrombolysis In Myocardial Infarction (TIMI) score, CHADS score (clinical prediction score for estimating the risk of stroke in patients with atrial fibrillation), and Wells' Criteria. If these clinical systems could be integrated with a computerized version of the ACR-AC, referring physicians would have a powerful and efficient tool at their disposal for the optimization of diagnostic imaging utilization in the palm of their hand.

CDS and CPOE are typically integrated into the hospital EMR system and accessed largely at hard-wired computer terminals, limiting their access and utilization. With the advent of smartphones and touch-screen tablet devices, there are many avenues in which to advance the mobility of CPOE with integrated CDS. With all of the benefits of mobility offered by smartphone- and tablet-based CPOE, future physicians would have a veritable "super tool" of evidence-based clinical support and order entry quite literally at their fingertips.

More distant future applications can be postulated as well. One potential future direction could include voice-recognition software combined with a "personal assistant application" (PAA) capable of query-response, perhaps in a conversational format. One such framework that is currently in existence is Apple's Siri application for some iPhone smartphones (Cupertino, CA). The role of natural language processing in CDS software has been discussed previously and deserves a reassessment at this critical juncture (19). Theoretically, a busy emergency physician could verbally order a study and include the clinical indication by speaking the patient's pertinent medical history, such as "34-year-old female presents with sudden-onset right lower quadrant pain, negative pregnancy test." Given the relative ease of use, such a system would likely facilitate a more descriptive and complete history, compared with histories entered by use of the keyboard.

Future Applications

One could imagine a referring physician querying the PAA regarding the best choice of diagnostic imaging utilization. The follow example is similar to a CDS case previously published by Drescher et al (20), and it exemplifies the potential power of proper CDS application coupled with natural language processing.

> Physician: "I am concerned that my patient has a pulmonary embolism (PE). What is the best approach to objectively diagnosing this patient?"
>
> PAA: "Based on the EMR, I see that the patient's heart rate is >100 and that she has a previous objectively diagnosed PE per past medical history. Is PE the most likely diagnosis for this patient?"
>
> Physician: "It is."
>
> PAA: "Has she been immobilized for at least 3 days, or has she had surgery in the previous 4 weeks?"
>
> Physician: "She has not."
>
> PAA: "Does she currently have any hemoptysis?"
>
> Physician: "She does."
>
> PAA: "And, finally, has she had any malignancy with treatment or palliative care within the last 6 months?"
>
> Physician: "She has not."
>
> PAA: This patient has a Wells' score of a least 7, placing her in the high-risk group for likelihood of PE. Is she pregnant?
>
> Physician: "Yes, she is currently 8 weeks into her first pregnancy."
>
> PAA: Does the patient have leg swelling?
>
> Physician: "Yes, unilateral on the right."
>
> PAA: According to the ACR-AC, the best approach to her imaging would be a lower extremity ultrasound with Doppler to search for potential sources of venous thromboembolism. Per the ACR-AC, an X-ray chest can also be beneficial to exclude other causes of acute chest pain, followed by a Tc-99m ventilation-perfusion scan with ventilation done only if necessary. If you would like, I can order a stat lower extremity ultrasound with Doppler. Would you like me to do so?
>
> Physician: "Yes. Please also alert the radiologist to contact me as soon as the results are available."

PAA: “Confirmed. I have ordered the imaging study, and have placed a high-priority call back alert for the interpreting radiologist.”

DATA ACQUISITION AND TRANSMISSION

Historical Model for Radiology Image Acquisition and Transmission

Radiology data acquisition has evolved over the past several decades. The field of radiology today is different from the early days of medical imaging, when portable roentgen examinations may have involved the radiographer viewing an image directly off a fluorescent screen (21). For many years, images were acquired with large machines that were relatively immobile and usually housed in the radiology department. Images were recorded on film, which was processed in the radiology department and then presented for interpretation on lightboxes. Under this model, anyone seeking to view the images required a physical copy of the film. In recent years, many radiology departments have been switching to PACS for image viewing and storage. To date, most radiology examinations are transmitted to PACS using hardwired networks.

Over the past several years, wireless network technology has demonstrated increased reliability and speed at a decreased cost. Consequently, the traditional models of data acquisition and transmission warrant reconsideration. Advances in mobile computing technology and hardware for data acquisition and transmission have the potential to revolutionize radiology. Several possible applications of new mobile computing technology are described next.

Digital Acquisition and Transmission of Radiographs

Many new portable radiography units have the capacity for direct radiography, bypassing analog translation in favor of the generation of a binary signal (22). Images acquired using these units are stored digitally on the unit until they are loaded onto PACS. As the data on such units are digitized at the time of acquisition, these images may potentially be transmitted to the PACS by the radiographer at the patient’s bedside, minimizing the delay between image acquisition and availability on PACS. While this technology is already used in practice to a limited extent, it has not yet in common clinical use. While it may not necessarily be efficient for the technologist to process/transmit the image and complete the modality performed procedure step for each image immediately after acquisition, this may be worthwhile for “STAT” examinations or studies where the radiographer notices a critical abnormality on the image and rapid radiologist review is needed.

Digital Acquisition and Transmission of Ultrasound

Diagnostic ultrasound is often performed with the use of wheeled units that may be used for portable examinations outside the radiology department. The images are typically discussed with the radiologist after the technologist has returned to the radiology department and loaded the images onto the PACS. This method of data acquisition is suboptimal as the interpreting physician may request additional images. It would be preferable for the radiologist to view the images while the sonographer is at the bedside in real-time or just after completion of the examination. This would facilitate tailoring the examination to the patient’s imaging findings. Images may be transmitted to PACS using either hardwired or wireless connections. Note that while this is already being performed at some institutions, it is not yet in general clinical use.

Consider the following clinical scenario: A radiologist is working during the evening in the radiology department’s reading room. She is called by an ultrasound technologist evaluating a patient in the ICU performing a portable exam, with the following verbal exchange:

Technologist: I am currently upstairs imaging Mr. X and have his images available for review.

Radiologist: It seems the patient is febrile and his doctors are worried about cholecystitis. Please let me see the images you have acquired.

Technologist: Most of the images are fine; however, there was bowel gas that limited some parts of the exam.

Radiologist: The gallbladder looks okay… Actually, is that a mass in the liver?

Technologist: I do not recall seeing one.

Radiologist: Let’s switch to real-time transmission to PACS. Now image the liver on midline. Good, now rotate the probe by 90°. Slow down… There!

Technologist: Wow, that’s subtle. Thank you for pointing it out. I will get some more images showing the largest dimensions and send them to PACS. Do you want anything else on this patient?

Radiologist: No, that should be fine. How do things look for the rest of the evening?

Technologist: Next I will be performing a renal ultrasound on a patient with a known stone and worsening abdominal pain. I will call you once I have images.

Radiologist: Thank you.

Portable CT and MRI

In addition to radiography and ultrasound, which have been acquired portably for many years, other imaging modalities have recently developed portable/mobile counterparts. Portable CT recently made its debut. There are currently units available for purchase by several manufacturers. These scanners tend to be small and restrict imaging to small structures such as the head. Portable CT units have been used in the pediatric population as well as in the intensive care unit setting, where it may be difficult or even dangerous to transport the patient to radiology for imaging (23).

Mobile CT and MRI have also been available for several years (24). These units resemble their stationary counterparts in radiology departments but may be installed in trailers and transported to locations remote from the hospital. While these units are not portable in the same sense as the portable radiography and portable ultrasound units, they do offer access of advanced imaging to patients in remote locations who may lack adequate transportation and resources. Transmission of data over high-speed networks allows radiologists to view the images minutes after they are acquired.

Remote Notification for Portable Examinations

The workflow of radiology technologists performing portable examinations is often suboptimal. The technologist may leave the radiology department with a printed copy of requested portable examinations, only to be notified shortly thereafter of additional emergency examinations conveyed via pager or telephone. Such a model is personnel intensive and prone to error. Advances in mobile computing offer the opportunity for significant improvement in this process. The portable radiography and ultrasound units may potentially be equipped with computers showing a real-time list of requested portable examinations and their priority. This would eliminate errors in the oral communication of new exams and likely be more efficient. While such technologies are already available, they are not in general clinical use.

Bringing Radiology to the Patient

The current general model for medical imaging requires that patients travel to an imaging center to have their examinations performed. The advances in mobile imaging technology open a new vista for medical imaging on a more personalized level. In principle, smaller communities without stationary imaging facilities could be serviced by "mobile radiology departments." Imaging could be conducted on the local level and then transmitted via high-speed networks to the radiologist for near contemporaneous reads. Such mobile departments would offer greater convenience to patients, as patients who are ill may be less inclined to make long trips when they could receive similar services in their own community. The application of this technology will likely be multifactorial, and dependent on not only the technology but also the way in which future health care is delivered to patients and reimbursed.

The "multicorder" and beyond

Imagine a single handheld device, the "multicorder," that could record all a patient's vital signs, as well as perform other functions including ultrasound. Many fans of the television show *Star Trek* will remember the "Tricorder": Dr McCoy would wave a small device over a patient's chest and gather extensive amounts of medical information via unknown means. While our technology has not evolved to this level, we are nearly able to record all a patient's vital signs with a single handheld device. In many respects our current mobile computing technology has already surpassed the science fiction of the past. Since the announcement of the competition for the Qualcomm Tricorder X Prize, many devices have been developed that approximate this fictional device. As our way of thinking about medicine continues to evolve and incorporate the latest technical advances, it is likely that we will see devices such as the "multicorder" appear in routine clinical practice and help us care for patients.

RADIOLOGISTS

Mobile Teleradiology

New legislation mandates the digitization of medical data, such as the implementation of EMRs as mandated by the Patient Protection and Affordable Care Act (25). These changes in national policy will facilitate electronic access to patient data and allow for new applications of computers and mobile computing in radiology. One of the factors previously limiting the application of mobile technologies to radiology was the limited resolution and contrast of mobile images. Recent studies have examined using mobile computing for viewing medical images have demonstrated that mobile devices fare reasonably well with regard to image viewing and interpretation when compared with monitors at stationary terminals (26).

Current hardware and software capabilities support the increased use of mobile technologies for diagnostic imaging interpretation. While, the exact role of mobile computing remains unclear, there are several potential applications. It is unlikely that radiologists will use mobile devices as their standard platform for image interpretation. However, mobile computing may be useful for image interpretations by on-call radiologists who are not at a hardwired PACS, allowing for rapid evaluation of urgent imaging studies with minimal delay.

Radiology Consultation and Reference Materials Using Mobile Computing

Mobile computing may also be useful for radiologic consults between radiologists and between a radiologist and referring clinicians. A radiologist-to-radiologist consult would be useful when the on-call interpreting radiologist may need some immediate assistance from a subspecialist. Mobile computing could also permit a new level of social availability for radiologists to clinicians. Mobile technology could facilitate bedside rounding with clinical teams or intraoperative discussions of imaging. By remotely accessing PACS, mobile computing could also promote social interaction between radiologists and clinical physicians and facilitate radiologist inclusion in the patient care team.

As radiologists are demonstrating an increased presence in medical school curriculum, there is a niche for mobile computing in the education. With the Osirix (iTunes, Apple) program, deidentified PACS images can be displayed on iPads and used in an educational setting, such as the gross anatomy lab or during small-group teaching sessions during elective radiology rotations.

Critical Notifications and Mobile Computing

One area where mobile technologies may be invaluable in the daily workflow of radiology is during notification of critical results. Incorporating a critical notifications system complemented by relevant images or annotations would improve communication with the referring physician. This may be accomplished using a radiology notification application installed on referring clinicians' smartphones. By providing timely, critical information complemented by a brief message, discussion, or video chat, radiologists may be able to provide improved service clinicians and patients.

EDUCATION

Introduction

Many current medical students and residents grew up with a high level of familiarity with electronic media. The term "millennial learner" has often been applied to younger students and is an umbrella term referring to students who turned 18 in or after 2000. Many of these students may be more familiar with learning via electronic media than with printed media. Consequently, more educators are adapting to fit the unique needs of these learners (27,28). Many current residents, molded by a culture of the Internet and mobile devices, respond well to novel teaching methods emphasizing multimedia and technology.

E-books and Journals

Mobile computing offers cutting-edge educational opportunities for resident physicians as well as practicing radiologists. The medical community has been quick to adopt mobile technology, with a survey of health care professionals in the year 2011, showing that 79% use iPads for work. Of radiology residents in particular, 74% owned smartphones and 37% owned tablet computers (29). There has been a proliferation of e-books and radiology-specific applications. Unlike printed media, these e-materials contain high-quality digital images, are often updated with current information, and are readily accessible. The portability of mobile devices allows a more user friendly platform than traditional textbooks. When integrated into residency education, tablet computers have resulted in a significant increase in the use of electronic educational resources (30). In this setting, certain applications have flourished, including e-Anatomy (www.imaios.com/en/e-Anatomy), RadPrimer (http://www.radprimer.com), and Radiology 2.0 (One Night in the ED, available on iTunes).

Tablet computers offer more than just portability and accessibility of traditional content; they offer the significant advantage of dynamic images. A journal article of the future might not contain just a sample static ultrasound image through the liver but rather a stack of Doppler images showing blood flow in the portal vein. Articles might contain embedded animations to explain a process better than static images, rather than distributed as supplemental downloadable content as currently offered by several journals.

Continuing Medical Education

The proliferation of radiology-specific applications also has implications for continuing medical education (CME). With the implementation of the American Board of Radiology Maintenance of Certification program, diplomats with time-limited licenses are now required to take a practice profiled examination every 10 years as well as obtain CME and self-assessment module credit. The content-rich practice profiled examination will encourage the continued development of content-rich and interactive CME activities. The accessibility of these tools via a mobile platform would be a useful adjunct to tools available on desktop computers. Educational modules with CME quizzes on mobile devices could be accessed during commutes on mass transit or other travel, allowing for productive use travel time and minimizing time spent on CME while at home. Prominent radiological web sites such as the ACR Case-in-Point and Aunt Minnie have already begun making mobile versions and applications for their web sites, providing quick and reliable access to cases of the day, news, forums, and other dynamic content.

Resident Assessment

Mobile computing also has the potential to be integrated into residency assessment. The Accreditation Council for Graduate Medical Education has introduced an outcomes based evaluation system to assess the core competencies and radiology milestones of resident physicians. Radiology residents will be assessed on their abilities to achieve milestones in the clinical competencies: Patient Care and Technical Skills, Medical Knowledge, Professionalism, Interpersonal and Communication Skills, and System-Based Practice. Future assessment of residents in areas such as Professionalism and Interpersonal and Communication Skills will include 360° evaluations requiring information from patients, fellow residents, nurses, technologists, and attending physicians. It is sometimes challenging to get timely resident evaluations as the evaluator may not be able to access a hardwired terminal and/or may have to go through several steps at a terminal to access an evaluation. Mobile devices with a dedicated evaluation application may allow for more immediate and accurate evaluations of resident performance. For example, a technologist with a mobile device would be able to log an evaluation of a resident immediately after their interaction, or an attending physician may be able to enter a procedural evaluation of a resident in real time, while the procedure is being performed.

Online Teaching Conferences

Online teaching conferences present another promising application for mobile computing. Faculty members, alumni, and residents are often working at multiple sites, limiting in-person participation in didactic conferences. Using applications such as Citrix GoToMeeting, which runs on major portable and desktop computing platforms, successful multi-institution conferences have been established (31). This allows participants at remote sites to participate in educational activities and has fostered collaborative educational projects. The availability of such applications on a mobile platform would allow for greater access and may improve "virtual" conference attendance.

Radiology, by virtue of its image-intensive content, is well situated to lead the development of mobile educational resources, and the rapid adoption of mobile technology is promising. A future dominated by novel electronic educational resources is on the horizon, resources that will immerse the user in an interactive data set rather than static sample images. The ability to participate when a dedicated stationary desktop device is not available would facilitate participation.

Procedural Training

Other novel applications for mobile devices in education are being explored. A new software application takes advantage of the accelerometer in cell phone devices. Techniques for performing ultrasound-guided needle skills can be improved with this mobile technology (32). Similar products have been used to improve spatial and anatomic awareness in ultrasound. Such hands-on training using mobile devices may allow for more rapid acquisition of tactile skills and hand–eye coordination needed for patient care. Such technology would also likely be more affordable, as it would not require the purchase of dedicated hardware.

APPLICATIONS AND IMPLEMENTATION IN PATIENT CARE

The Increase in Mobile Technology Use by Nonphysicians

As EMRs are implemented across health care enterprises, there is a push for integrating the patient into the health care network. These patient care information systems (PCISs) are broadly defined as applications that support the health care process by allowing health care professionals or patients direct access to scheduling, order entry systems, and medical records including imaging reports (33). PCISs are described in patient safety literature as one of the core building blocks for a safer health care system (34). A 2011 Nielsen survey indicated that more than half of 18- to 34-year-olds owned a smartphone (35). In 2011, more than 5.6 billion people worldwide were using cell phones and smartphone purchases had outpaced computer purchases. A 2011 Manhattan Research survey indicated that 81% of surveyed physicians used at least one smartphone, 75% had downloaded at least one application, and 30% were using an iPad to access EMRs, view images, and communicate with patients (9). The demand for digital medical interaction is expected to increase as this tech-savvy generation begins to use more health care resources. Research suggests that the market for mobile computing devices in the health care market will grow from $100 million in 2011 to $1.7 billion in 2014 (36).

Clinic Logistics

Online patient scheduling is now being offered at an increasing number of health care facilities in an effort to increase efficiency and improve patient satisfaction. This model allows a patient to access the clinic's web site and select a convenient appointment in real-time (37). Digitally literate patients are expected to find this experience similar to making online reservations for airline tickets, hotels, and restaurants (37). Imaging services often require timely scheduling, patient questionnaires, and even precertification. Just as patients may "check-in" for a flight while in transit to the airport, so, too, can the technology be leveraged to improve the efficiency with which outpatient imaging and procedures are performed.

The indirect cost of "no-shows" has led to the investment in expensive and inefficient telephone and postal mail systems dedicated to appointment reminders. For example, an appointment confirmation may be sent via a dedicated application, e-mail, or text message and received with a smartphone or other mobile device. Such a method could save many person-hours of reminder phone calls or envelope stuffing as well as postage. If patients forget the appointment time, they can confirm this through the mobile patient portal. Such a form of convenient scheduling may invite earlier notice of cancellation and better utilization through add-ons (37). Patients could even be placed on "stand-by" and sent a text or e-mail alerting them of an opening while out shopping. Conversely, a message could alert them to a delay in the day's schedule and allow them to stop for an errand before arriving.

Waiting rooms already have consoles to facilitate a digital check-in process. The next natural step is to offer check-in across Bluetooth, NFC, or WiFi and, once checked in, allow them to peruse informational media regarding the procedure or examination they are soon to experience. At departure, satisfaction surveys could similarly be sent to their mobile device at check-out to increase response immediacy and frequency.

Results Communication

EMRs. As open medical records and other PCISs are made available, patients will likely request access to their imaging results. Patient portals could be accessed on either a personal computer or mobile device. The patient portals may be integrated with the organizational electronic health records, which facilitates medical record documentation of communications and can help the organization meet the Centers for Medicare & Medicaid Services Stage 1 Meaningful Use requirement for sharing health information with patients electronically (9).

Hospitals that introduced EMRs have already implemented patient health information protections by employing encryption, authentication and authorization controls, and audit trails (38). As patient portals are developed, it should be feasible to implement a similar interface for patients to access their radiology reports. Furthermore, the patient could be provided a link to educational information about reflux and hiatal hernias. The Mayo Clinic has already developed such a database of disease information intended for patients (39).

Electronic access to images. There are, however, some pitfalls to providing digital reports directly to patients. Radiology reports often contain medical jargon, which may be difficult to understand and cause unneeded anxiety for patients who are not in the medical field (40). Comments such as “limited by body habitus” may have to be reworded as they may be misinterpreted. Most physicians would probably agree that care should be exercised when informing patients about potentially devastating results such as new cancer diagnosis. This complicates the notion of immediate full patient access to their medical records. Such information should only be disclosed in an appropriate setting where appropriate support is available. Important findings may instead be forwarded to the referring clinician such that they may be able to discuss the results with the patient directly. Recent studies show that older patients are reluctant to receive medical results digitally, preferring telephone or postal mail delivery, while younger patients were significantly more interested in electronic delivery (41,42). There is also a socioeconomic disparity to overcome as less educated and financially disadvantaged patents are less likely to have Internet access or computer literacy (41).

Patient Education and Compliance

Empowering patients with mobile technology could increase patient adherence as well as improve overall health outcomes. It has already been shown that mobile technology offers the chance to deliver key health messages outside the context of intermittent office visits (43). For health care practitioners, the use of mobile information technology can bring additional resources to the point of care. Many organizations provide patients with their medical information on a digital USB device. Organizations such as Kaiser Permanente offer their patients a “portable EMR” whereby a summary of medical information is available and accessible from any computer.

Physicians can use mobile technology to counsel patients via mobile alerts. For example, Aetna and Columbia University dentists worked together to developed a smoking cessation program built for the iPad (44). Radiologists could offer the same type of education and empowerment by encouraging patients to learn about their disease process and management. For example, if a patient with a small lung nodule is recommended to return in 6 months for a follow-up CT, the patient would have already seen their images, report, and recommendations for follow-up. Patients could read about lung nodules on the hospital network and make their follow-up CT exam appointment by mobile device, automatically adding the appointment to their calendar. Then, an e-mail or text reminder would precede their follow-up radiology appointment.

BARRIERS TO ACCEPTANCE AND STRATEGIES FOR SUCCESS

Implementing mobile computing solutions in radiology will require attention to potential barriers to acceptance. As with many new technologies, there will be technological and social challenges that need to be addressed. It is imperative that existing hospital information technology departments are involved in the planning stages. Barriers to early adoption for patients and physicians include availability of necessary hardware and software, a lack of familiarity with the technology, fears about information security, and standardization across health care networks. The successful integration of mobile computing technologies into radiology and medicine will depend on overcoming these obstacles.

Familiarity with Mobile Technology

A lack of familiarity with an online health portal could hinder use by patients. Studies have shown some patients are reluctant to receiving digital health results (41,42). These and other studies suggested a trend for younger patients to be more accepting of electronic delivery of health information (41,45). Kaiser Permanente has reported that 63% of its eligible membership (approximately 4 million patients) have used their online health portal to review lab results, order prescription refills, and even e-mail their provider (46). In addition, the US Census Bureau found that the one of the most common reasons to access the Internet in all households was to search for information about health care (47).

Information technology advances in medical imaging are greatly affected by the specialized security requirements needed for handling protected health information (48). Hospitals with EMRs already have secure internal wireless networks that can be used to transmit protected health information. The Food and Drug Administration recently approved mobile computing devices for use in diagnostic imaging (49). In addition, even though patients express concerns about security of electronic health systems, many patients eventually adopt these systems (50).

Overcoming these obstacles will likely involve a certain amount of education of both physicians and the lay public.

Online reference materials and courses would be useful to assist with education. Highlighting the advantages of mobile information access will likely be a motivating factor for greater acceptance. With time and exposure, it is likely that there will be gradual adoption of mobile technologies in medicine.

Standardization of Information Format and Integration

EMRs have not yet solved the problem of redundant and incomplete medical records for patients who use different health care networks. Medical imaging has been a pioneer in the standardization of medical records with Digital Imaging and Communications in Medicine, the accepted diagnostic imaging format standard for nearly 30 years (51). Since most images are transmitted in this format, standardization of images should not be a problem. However, each health care system may have a different EMR or RIS, which will present barriers to reporting findings or accessing a patient's history. This will likely limit the application of mobile computing in radiology to those providers within a single health care system.

Although attempts are being made to standardize health care informatics—as with HL7, an interoperability standard—it may ultimately prove to be patient demand that forces the issue. Once patients begin to wonder why they cannot freely share and save their medical information online and through medical devices, the medical industry will likely be motivated to respond. Nascent cloud-based EMR and PACS efforts are an example of this.

Information Security

Data security and Health Insurance Portability and Accountability Act of 1996 violations have been a major source of concern for the digitization and online sharing of health information. Regulatory hurdles loom large for companies and institutions interested in pursuing new devices or applications. As with other forms of health information, the information should be accessible to the patient but secure from others, unless otherwise delegated to have access. To ensure the security of mobile data, health care organizations must provide effective methods such as strong access controls both at the device and network levels and secure identification and authentication, and systematic auditing. The safest strategy is to allow applications to view data locally on the mobile computing device but not permit the storage of sensitive data without strong encryption. This ensures that the user views only the latest data available and protects the patient from unauthorized use of data should the device be stolen or lost (9).

Current confidentiality and information security policies will have to be reviewed and revised so that the user is prohibited from storing protected health information on their personal mobile device and prohibited from sharing their mobile devices. Informed consent between the provider and patient may also be helpful to ensure that the patient understands the risks of mobile access to their data. The consent may include a discussion of the platform (e-mail, patient portal), the risks of e-communication, appropriate use guidelines and conditions of participation, and user authentication (9). Clear guidelines for appropriate use should also be established, based on the platform. For example, specific new diagnoses (HIV, cancer, other potentially terminal illness) would not appropriate for an automated e-communication platform (9).

Demonstration of Economic Feasibility

In theory, a medical center or imaging practice must justify the expenditure of incorporating mobile computing by demonstrating quantifiable benefits that exceed capital costs. In practice, however, ease of use and efficiency often prove paramount. For example, it is unlikely a new hospital being built will consider the "value" of wireless internet given its near ubiquity at most modern institutions and the associated user demand. The most compelling arguments can be made with metrics demonstrating improved equipment utilization, decreasing the turnaround time, increased availability or subspecialty reads, and decreased cost. Therefore, specific research will need to first estimate the potential benefits of a particular mobile computing system and evaluate the quantifiable benefits of the mobile computing system.

The incorporation of mobile computing technology in health care increases capital cost but may reduce operating costs. For example, electronic portals would decrease the costs of generating and mailing paper letters, and offer the possibility of closed loop reporting without the need of follow-up telephone calls. Assuming a certain level of platform standardization, health care organizations can build web-based clients according to standardized protocols and limit redundancy of development. For example, today most medical app developers may only develop apps for iOS (Apple: Cupertino, CA) and Android (Google, Mountain View, CA). Institutions may take advantage of device ubiquity to reduce the number of devices the organization itself must provide, thereby decreasing costs. With a single mobile device, training costs go down compared to the costs to support many devices (9).

The Role of Research

By developing a framework or model for understanding the role of mobile computing in radiology, individual components can be systematically evaluated and deployed to determine their effectiveness. When one organization identifies a successful application of mobile computing to radiology, other practices will be able to learn from the example and emulate its success. Publication of the methods of mobile computing utilization and implementation will serve as a guide for other institutions looking to adopt a similar model.

Fifty Years in the Future

Advances in information security and data encryption will allow for safe transmission of protected health information to wireless devices. Requirements for securely accessing data may well be biometric identifiers such as a fingerprint or retina scan. There may be a standardized EMR that allows all health systems to access a person's records from a central database so there is never redundancy or missing information.

CONCLUSIONS

The rapid advances in mobile computing technology present both challenges as well as opportunities to radiology. These new technologies offer opportunities for improved patient care while simultaneously facilitating the workflow of radiologists and referring physicians. Given modern radiology is a very technologically intensive field, we find ourselves the vanguard of clinical medicine as it seeks to adopt emerging mobile computing technologies. This position offers radiologists the opportunity to be leaders of this new era in medicine.

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