Since the turn of this century, digital wireless devices have had a profound impact on how we communicate, read, listen to music, play games, and even think. Now, in the coming decade, we are poised to see digital wireless medical devices have a radical, transformative effect on the future of healthcare.

In-Hospital Wireless Medicine

The rebooting of healthcare to integrate wireless technologies will occur at many levels. First, the in-hospital landscape will be markedly changed. Rather than the intensive care unit being the sole place where frequent vital sign measurements are recorded, every hospitalized patient’s heart rate and rhythm, blood pressure, and other vital signs will be continuously monitored by noninvasive wireless sensors in the form of Band-Aid-like adhesive strips on the skin or wrist transceivers. Furthermore, wireless accelerometers that monitor a patient’s position and activity at all times may help prevent falls and accidents.

The reach of wireless sensors extends well beyond vital signs and well beyond the hospital environment. Continuous glucose monitoring is now available; we know that achieving optimal glucose homeostasis in diabetics improves acute-phase, in-hospital outcomes for patients with heart attack or those undergoing major surgery. Physicians can now access the vital signs of hospitalized patients who are in the intensive care unit via their smart phones (Figure 1), and obstetricians can similarly monitor the uterine contractions and fetal heart rate of expectant mothers via their cell phones. Wherever there is connectivity to the web, patients can be monitored in real time.

In addition to monitoring, the quality of care in the hospital setting can be facilitated through wireless technologies. This includes the ability to track every medication that is ingested, using pills tagged with digestible sensors that are activated in the stomach by the change in pH. Skin patches incorporating a particular drug make it possible, via wireless activation, to administer a precise dose at a specific time for any patient. Wireless sensors can monitor even routine procedures, such as physician and nurse hand washing. Medical errors that occur in the hospital environment may potentially be reduced by integrating data from the electronic health record with the physiologic data provided by wireless sensors.

However, this newfound capability engenders major questions,
1. In March 2009, the Kaiser Health System published evidence in *Health Affairs* showing that the use of e-mail and telephone communications has cut visits per patient by an average of 26 percent, saving money and increasing the efficiency of care. It is likely that widespread adoption of e-mail will affect all providers similarly by 2016.

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2. Care for the socioemotional needs of patients, for example, those diagnosed with depression, will increasingly be provided by telephone or online. For example, one online service lets physicians see their patients at a time and place convenient to physicians. Patients are queued online so that providers can process 15 consults per hour. Such telephone and online access will be used by your hospital’s physicians in 2016.

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3. Patients with diabetes who use web-based case management programs, such as websites where they can access their medical record, upload blood glucose readings, create a daily activities diary, and generate care action plans, scored higher self-efficacy and empowerment scores than patients without access to such programs. By 2016 your hospital will have established web-based case management programs for at least half the chronic diseases cared for.

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4. Communication with referral sources and other providers will shift primarily from telephone, fax, and e-mail (from high to low rank) to social media, e-mail, and telephone.

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5. Hospitals with an average daily intensive care unit (ICU) census of fewer than eight patients will outsource ICU monitoring via telemedicine.

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6. To ensure that appropriate hand washing takes place, most of your hospital’s rooms will be equipped with wireless monitoring devices, that is, sensors and wrist badges worn by those entering and leaving the room.

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7. “Smart pills” contain a tiny computer chip that sends an electrical signal to a small bandage that reads and stores information. That information can then be transmitted to a device that updates the patient’s physician via e-mail. Smart pills will be widely used in your community to enable practitioners to monitor compliance with drug regimens.

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8. Drug delivery will be much more targeted. For example, a commonly available silicon chip will be able to store and release medication on demand. When a remote wireless signal is sent, a tiny electrical current will spur the chip to release a prescribed amount of the drug. Such technology will be commonly available for diabetics, heart attack patients, and those suffering from hypoglycemia, helping them manage their chronic diseases.

**Note:** Percentages in each row may not sum to 100% due to rounding.
**What Practitioners Predict**

**Physicians will adopt e-mail in caring for patients.** Eighty percent of respondents thought it likely that by 2016, all providers will use e-mail and the telephone to communicate with patients, resulting in a reduction in the number of patient visits and the costs of providing care. But respondents were divided as to the likelihood that their hospitals would adopt online services that would allow physicians to conduct up to 15 consults per hour.

**Hospitals will use the Internet to communicate with patients and referral sources.** Nearly three-quarters of respondents agreed that their hospitals will establish web-based case management programs for at least half the chronic diseases cared for. For example, patients with diabetes could gain access to their medical records, input their blood glucose readings, and generate care plans. More than two-thirds agreed that social media, followed by e-mail and the telephone, will be the most frequent way hospitals will communicate with referral sources by 2016. (Today, phone, fax, and e-mail, in that order, are the most frequently used communication vehicles.) But practitioners were divided on the likelihood that ICUs with fewer than eight patients on average would outsource monitoring via telemedicine.

**Practitioners are skeptical about widespread adoption of futuristic devices.** Nearly two-thirds of respondents did not think two monitoring devices asked about would be widely adopted by 2016. A device that monitors hand washing on entry into and departure from patient rooms was deemed unlikely to be adopted at their hospitals by 62 percent of practitioners. Another device, rejected by 64 percent, are “smart pills” that e-mail information to the patient’s physician to allow monitoring of compliance with drug regimens. Finally, respondents were divided on the likelihood that drug delivery will be more targeted (for example, by using a remote wireless signal to spur an embedded computer chip to release medication to patients with chronic diseases).

**Wireless Sensors in the Outpatient Domain**

The adoption of wireless devices in the outpatient practice of medicine has already begun. Congestive heart failure is the number one cause of hospitalization and hospital readmissions in the United States, with a rehospitalization rate of over 27 percent in 30 days and over 50 percent at 6 months in the Medicare population (Jencks, Williams, and Coleman 2009; Bueno et al. 2010). Strategies such as daily patient weigh-ins and telephone check-ins with nurses have failed to reduce this major problem.

Recently, the implant of a microelectrode mechanical sensor (MEMS) device into the pulmonary artery, which transmits blood pressure information via a wireless signal, has been shown to markedly reduce rehospitalizations (by 30 percent at 6 months and 38 percent at 1 year) in a randomized trial of 550 patients (Abraham and Adamson 2010). This suggests that a substantial benefit can be achieved by having more precise assessment of the patient’s hemodynamic status to...
guide the appropriate use of diuretics. If noninvasive sensors can replicate this magnitude of benefit, placing a Band-Aid sensor on the chest to measure the patient’s fluid status could prove to be a viable alternative to a permanent device implant.

A second area of innovation for outpatients is the use of Band-Aid sensors for monitoring heart rhythm. Currently, the most common way patients have heart rhythm monitoring is with Holter monitoring. However, the Holter monitor is a bulky device with multiple leads attached; it requires hookup and subsequent unhooking at a hospital or doctor’s office; and it keeps patients from being fully active. Most patients can tolerate this form of monitoring for only one or two days, and the monitoring is not real-time; a tape has to be reviewed to analyze the heart rhythm. Real-time monitoring for extended periods (weeks or a month) is available through systems marketed by CardioNet and LifeWatch, but these also involve multiple leads and are somewhat cumbersome for patients. Moreover, real-time monitoring is often not necessary and is quite expensive.

A new wireless entry for heart rhythm monitoring is the iRhythm patch, which can be mailed to the patient, placed on the chest skin for a week or more, and then mailed back. It is inexpensive (about $150 compared with $1,500 for the Holter monitor) and convenient. The iRhythm patch is a good example of the potential of innovation to substantially cut costs. In another encouraging study by the Veterans Administration health system, the use of widely available home telehealth disease management for a variety of chronic conditions—including diabetes, chronic obstructive pulmonary disease, congestive heart failure, and hypertension—led to a 20 percent to 30 percent reduction in resource utilization (Darkins et al. 2008).

**The Impact of Mobile Medical Imaging**

A revolution in ultrasound imaging is also taking place. The Vscan, the first pocket, miniature, high-resolution ultrasound device (Figure 2), was released in the United States in February 2010. Vscan images approximate the quality of the standard, expensive, hospital-based system (Liebo et al. 2010), which usually costs $250,000 to $300,000. The Vscan currently sells for $7,500 and can be incorporated into the routine physical examination.

More than 8 million echocardiograms are performed in the United States every year; it is easy to imagine that a substantial fraction of these could be preempted by use of a Vscan. The device also can be used for ultrasound examination of the abdomen or fetus. The Vscan is not ready for rapid wireless transmission yet, but once that capability is achieved, it will be possible for emergency room physicians to acquire the images and transmit the video to specialists for rapid interpretation. Similarly, paramedics in the field assessing patients with trauma or possible heart attack could transmit ultrasound images to physicians to get the hospital prepared.

Accordingly, mobile, miniature, high-quality ultrasound imaging presents exciting new opportunities for improved healthcare. What’s more, the use of “free” screening echo examinations—free in that

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**Figure 2.** The GE Vscan is a pocket, miniature, high-resolution ultrasound imaging unit that can be used for echocardiography or ultrasound of the abdomen or fetus. Courtesy of GE Healthcare.
there is no reimbursement set up for the rapid ultrasound scan—might prove to be a remarkable cost reduction.

Moving Toward e-Visits
While sensors and advances in imaging are a major part of the wireless medical leading edge, the ability to conduct office visits over the Internet also needs to be highlighted. Texting and e-mailing have already been shown to be effective tools to connect patients and physicians efficiently, as a Kaiser study of over 35,000 patients with hypertension, diabetes, or both nicely documented (Zhou et al. 2010).

A parallel study by Kaiser showed that the use of e-mail communications and telephone visits cut office visits by 26 percent, improving the efficiency of ambulatory care (Chen et al. 2009). In these studies, which used the secure e-mail messaging functionality of Kaiser Permanente’s nationwide comprehensive electronic health record system (known as KP HealthConnect), management of these conditions improved, and perceptions by patients and physicians were positive.

Taking these advances many steps further to the concept of virtual medical practice, Dr. Jay Parkinson in New York City has set up a Facebook-like platform known as Myca Health, which enables video visits and instant messaging along with conventional, face-to-face office visits (Salter 2009; Hawn 2009). The Myca platform has been remarkably popular, and the e-practice of medicine is spreading to many other regions of the country.

The widespread availability of software such as the FaceTime app on the iPhone, which permits high-definition video calls, and high-resolution cameras on smart phones facilitates such video office visits. These innovations, coupled with the ability to transmit vital signs and other metrics via wireless sensors, raise the realistic possibility that much routine office care for nonacute conditions could be handled by such links. This opportunity to improve efficiency, for both patients and physicians, is especially important in the face of the growing physician shortage.

Implications for Hospital Leaders
Consider wireless real-time monitoring. Awareness of the capabilities of wireless sensors for in-hospital monitoring should lead to advance planning about whether to provide continuous vital sign monitoring for beds not currently in intensive care or step-down, telemetry units—areas where special machines are used to help staff closely monitor patients, especially for changes in blood pressure and heart rate and rhythm. Besides whether to monitor such beds, decisions need to be made about the type of monitoring—heart rate alone, heart rate and rhythm alone, or complete vital signs with continuous blood pressure, oxygen saturation, respiratory rate, and body temperature. Also, consideration should be given to whether to use continuous glucose monitoring in diabetic patients who are critically ill or are undergoing major surgical procedures.

Beef up IT support. Related to in-hospital monitoring, hospital leaders will be faced with requests from physicians to follow their patients’ vital signs on their smart phones. This will require information technology support to ensure data security.

Look for technologies that improve care or lower costs. Emerging technologies such as the pulmonary artery pressure monitoring device or noninvasive wireless sensors have considerable potential to reduce rehospitalizations for such diagnoses as congestive heart failure. Devices such as iRhythm and Vscan also may lower costs and improve the quality of care. In addition, preparing for the use of mobile ultrasound by paramedics or emergency room physicians, with rapid connection to the appropriate specialist to review the images and provide feedback, is in order.

Get ready for e-visits. Finally, although most hospitals and health systems are not ready for e-visits and the extensive exchange of data between patient and physician by e-mail, texting, video, and real-time relay of wireless sensor data, it is time to prepare for some of the inevitable changes in the way the office visit and physician–patient communication will be redefined in the future.

Disclosures: Dr. Topol is on the boards of directors of DexCom, a company that manufactures wireless glucose sensors, and Sotera Wireless, which manufactures wireless vital sign monitoring devices.
References


