Medication adherence is one of the most complex and persistent challenges in healthcare, but emerging IT can play a major role in improving it. The authors discuss five major technologies for medication adherence.

IT is transforming healthcare. Telemedicine lets doctors diagnose distant patients and even perform remote surgery. Electronic health records make it easier to coordinate treatment among multiple healthcare providers; supply a comprehensive medical history of the patient to the treating doctor, thus enabling better diagnosis; and reduce costs by preventing redundant tests and treatments. Data analytics detects dangerous side effects or undesirable drug interactions and helps healthcare workers make data-based decisions. RFID chips prevent counterfeit medication from entering the supply chain and help hospitals keep track of their medical devices. Although IT makes many contributions, one of the biggest healthcare challenges—and greatest opportunities for IT professionals—is to improve medication adherence (MA).

MA is taking medication as prescribed by a doctor—that is, taking the right medication in the right dose at the right time. Only about 50 percent of patients adhere to their medication regimen well enough to receive the full benefit of their prescriptions. Each year, poor MA causes 125,000 deaths in the US and results in avoidable healthcare costs totaling $310 billion in the US and £100 billion in the UK. According to the US Surgeon General, “One way we can prevent serious health complications and even death is to ensure that people take their medicines as
directed. The World Health Organization argues that improving MA could have a greater benefit to global health than developing new disease treatments.

There are many reasons for poor MA, including undesirable side effects, a lack of involvement from family and friends, and forgetfulness. Many people cannot remember whether they took their medicine, especially those who take multiple drugs. Those who take a prescription after the scheduled time risk an overdose if they take it again at the next scheduled time. Other lapses are caused by inexact measurements by patients, as when diabetics approximate the ideal insulin dosage. Clinical trials show that effective long-term interventions address multiple factors.

Five types of wireless, health-related IT could profoundly improve MA: smartphone apps, smart medication boxes, smart pills, wearable sensors, and implantable devices. Together, this IT provides a roadmap for dramatically improving healthcare. The road begins with incremental improvements in MA and monitoring and ends with the transformation of how drugs are delivered and clinical trials are conducted.

**Five Frontier MA Technologies**

There are five frontier technologies for improving medication adherence: smartphone reminder apps and smart medication boxes are commercially available, but have not achieved mainstream adoption. Smart pills, wearable sensors, and implantable devices have been laboratory tested, but are still in the nascent stages of development or the regulatory approval process.

Smartphone apps to improve MA are already available for iPhone and Android devices. Some are designed to increase family involvement or provide educational information. Most are reminder systems that alert patients when it’s time to take their medication. They also record when patients take their medication or skip a dose. Once the patient confirms taking the medicine or indicates that the dose will be skipped, the reminders stop until the next scheduled time. The apps also stop reminding patients to take medicine when there will no longer be a safe time window between taking the current dose and taking the next scheduled dose. This contextual consideration helps prevent adverse medical reactions and overdoses. It also reduces the likelihood of patients becoming addicted to certain painkillers. Patients can share their adherence records during doctors’ visits. Some apps automatically send adherence information to the doctor.

Smart medication boxes incorporate IT into the traditional medication box filled by pharmacists or healthcare providers that indicates which day, or part of the day, to take the medication in a certain compartment. Smart medication boxes have a programmable reminder alarm that reminds the patient to take the medication. Sensors detect when the medication is dispensed, record the information, and send it to the healthcare provider.

Smart pills have digestible microchips embedded within the medicine. When a patient swallows the pill, the chips react with stomach enzymes to send a wireless signal to a nearby smartphone or tablet computer. Tracking software in the nearby device records that medication has been taken and sends the information to the healthcare provider. Smart pills represent a significant advance over smartphone apps, which rely on self-reported adherence data, and smart pill boxes, which can record when medication is dispensed but cannot confirm that it was taken by the patient. Smart pills confirm both the time and type of medication taken by the patient.

Wearable sensors use dry sensors, as opposed to the traditional hydrogel-based electrodes used in healthcare. These sensors allow long-term, continuous, and ambulatory monitoring. They can be worn on a patient’s skin, but noncontact sensors can be woven into clothing. Other sensors can be incorporated into commonly used objects. For example, sensors can be embedded in contact lenses worn by diabetic patients to monitor the glucose levels in their tears. Wearable sensors enable constant monitoring of vital signs and provide true context-aware alerts to take medication, based not only on timing but also on vital signs.

Implantable devices are embedded in the patient’s body. They can be linked to wearable sensors or might be a fully implanted system. For example, the glucose-monitoring contact lenses worn by diabetics can wirelessly signal an implanted insulin pump to adjust the insulin level. This would provide appropriate insulin levels at all times, rather than the medication peaks and troughs that occur with periodic dosing.
eliminates the need for error-prone human measurements. Fully implanted systems also offer great promise. For example, patients with chemical imbalances in their brains can benefit from electrochemical neuro-implants. These implants can sample brain chemistry in real time and release drugs directly into the parts of the brain causing problems such as depression.11

The Road Ahead
Although these five technologies each afford significant promise for improving healthcare through better MA, like most IT, the real benefits will come by networking and integrating them. IT is combinatorial, which means that various devices can achieve superior performance when used in combination. These five frontier technologies serve as the foundation for a roadmap. Figure 1 depicts this roadmap, which contains five stops, each marking a significant advance in the quality of healthcare. By the final stop, the century-old approach to pharmacology is transformed.

Stop 1: Reminders and Record-Keeping Systems
Every journey begins with a small step. IT professionals and healthcare providers are making progress toward the first stop, which is widespread implementation of reminders and simple record-keeping systems. This stage of the journey includes both smartphone reminder apps and the use of smart pill boxes that contain reminders. At this point in the journey, simple IT solutions help people remember to take their medication on time, and by recording when medication is taken, reduce confusion over whether they’ve already taken it. The technology requirements at the first stop need low-bandwidth network connectivity, modest CPU capability, and easy-to-use user interfaces. The adherence data information is not transmitted to doctors or other healthcare personnel. Even these simple IT systems offer great promise. Pilot programs have shown that basic mobile phone reminders can improve MA significantly.12 Despite the potential of simple reminder systems, the level of adoption remains extremely low.

Stop 2: Health Record Integration
The second stop on the roadmap integrates the adherence information recorded by devices with electronic health records. This stop has two phases. The first is a basic communication function through which the healthcare provider receives MA reports via email or Web portal. The second phase of integration is when MA data is imported into patients’ electronic health records, so all relevant healthcare providers can access it. Both forms of integration provide doctors with a more accurate history of patient MA. Doctors can use the information to better assess the medication and its efficacy. If the medication is not having the expected benefit, the doctor can assess whether the prescription is ineffective or whether the patient did not comply with the prescription regimen. This helps the physician make an important decision: keep the patient on the same medication or change it? If the medication is taken as prescribed but is not achieving its target results, the doctor might switch drugs, if an alternative is available. If the patient did not adhere to the medication regimen, the doctor can either counsel the patient and try another round of treatment, or switch to a less-effective medicine or one that might have more side effects but doesn’t rely on self-administration by the patient.
(for instance, a long-lasting shot administered in the doctor’s office).

Stop 3: Smart Medication Box and Smart Pill Integration
The third stop incorporates smart medication boxes and smart pills into the mix. Reminder systems will continue to provide reminders until the medication box is opened or the smart pill has been ingested. This provides a much more accurate history than self-reported reminder systems. Unlike the first stop, these technologies are deeply networked with healthcare provider information systems. Pill boxes and apps associated with smart pills can link with pharmacies to trigger refill requests. These devices are ideally suited for medicine-by-mail services, in which “reusable” medication boxes can be employed. The data automatically will be incorporated into the patient’s electronic health record. Smart medication boxes can time-stamp the dose-taking, record the number of attempts a patient made to take certain doses, adjust the timing between doses (based on previous dose consumption, the patient’s condition, and instructions from healthcare professionals), analyze the pattern of adherence, and detect the presence of other medications in its proximity, if any potential medication abuse needs to be observed based on the patient’s history or the type of medication.

Stop 4: Wearable Technology and Implants
At this point, the MA journey changes from one of meaningful incremental improvements in health outcomes to a transformation in how pharmaceuticals are tested and administered. Like stop 2, this part of the journey has two phases. The first phase is the incorporation of wearable sensors. These sensors measure vital signs and are linked with a medication reminder system. The system links taking medication and the subsequent physiological activity. The sensors can be woven into clothing or something as simple as a high-end smartwatch. This provides information for doctors to optimize prescribed medication regimens based on an individual’s response to the drugs. Whereas smart pills overcome the inaccuracies inherent with self-reported behavior, wearable sensors enable matching medication consumption with the corresponding physiological reaction at the individual level. Although sensorized clothing is available, this stop remains a distant destination because few devices have been operationalized outside the laboratory setting. Those that have mainstream acceptance, such as Fitbit, are not certified for use by healthcare providers.

The second phase of this stop is the use of implantable health IT. Implantable technology will transform healthcare. Linking continuous, real-time vital sign monitoring with the real-time administration of medication will provide tailored drug doses and the optimal amount of medication at all times. Patients will still need prescription refills, but with wireless integration with pharmacy ordering systems, this problem will mostly disappear. Additionally, providing optimal doses based on actual vital signs will reduce the likelihood of negative side effects. With fewer side effects, fewer people will intentionally avoid their medication.

Stop 5: R&D Integration
At stop 5, IT combines gains made along the road and provides the catalyst for transforming pharmacology. Electronic health records, adherence data, and data from wearable and implantable sensors are anonymized and stored in a database for medication researchers and pharmaceutical companies. Qualified clinicians can mine this big data for new insights. This will improve drug safety because the large datasets will help epidemiologists and other data analysts identify negative side effects that weren’t uncovered in initial clinical trials. Data can show the optimal dose amounts and frequency based on actual patient experiences. Analysis can also identify favorable unintended benefits—positive side effects—that can be used to treat other conditions and improve quality of life. Robust datasets from actual patient experiences can provide a cost-benefit analysis of competing medications used to treat the same conditions. Healthcare providers and patients can make evidence-based decisions regarding which treatments will be more effective and decide whether the high costs of some medicines are justified.

Reaching the Destination
Although implantable devices are still in their infancy, the other technologies at the frontier of MA are available. The grand challenge is making them all work together. Whereas the big picture is
easy for technologists to visualize (see Figure 2). IT professionals will be the ones to integrate the disparate hardware and software systems and address the problems that arise during systems integration projects. Part of the integration challenge will be creating systems in which interventions can be individualized based on a patient’s needs. For example, people who establish patterns of proper adherence might stop receiving reminders unless they miss a dose. Similarly, implantable devices would only be used for hard-to-treat conditions that benefit from constant monitoring and high-frequency dosing.

Table 1 summarizes the stops along the road ahead along with the basic system requirements, MA frontier technologies, and wireless networking technologies that can be used to integrate them. For example, widely available 3G networks can support reminders, whereas the faster 4G (and future 5G) networks are more suitable for personalized, smart, and context-aware reminders because of their ability to store and process complex information, their high-speed network access, and their better and bigger device displays.

IT professionals need to overcome several challenges: the high cost of some solutions, reliability and usability of smartphone applications, limitations of mobile devices, wireless network access and reliability, varying bit rates and data traffic, complexity of protocols and communication reliability for short-range communications, and end-to-end security for sensitive medical information. Work is needed to address system and technology scalability to include the great variety of patient types, medications, conditions, and applications. More work can also be done toward defining, designing, and implementing application-specific quality of service for both unicast and multicast communications and the degree of personalization offered.

Several optimizations can be designed and implemented to reduce the amount of data that must be entered by patients and family members or transmitted between devices and servers, and to apportion the processing between various devices and servers. These can be modeled, simulated, and tested with real patients in different

Figure 2. Overview of digital medication adherence transformation. Integration of different hardware and software systems will provide a robust environment for medication adherence.
environments involving different health conditions, applications, and possible interventions.

The roadmap presents many challenges, but the destination—dramatically improved healthcare outcomes—makes the journey worthwhile. Difficulties arising from developing interoperable standards, implementing security protocols, and advancing adoption by disparate stakeholders, including patients, doctors, hospitals, insurance companies, and national health services, are problems that IT professionals are best suited to address.

### References


### Table 1. Summary of the roadmap to medication adherence.

<table>
<thead>
<tr>
<th>Road stop</th>
<th>Requirements</th>
<th>Possible technologies and networks</th>
<th>Comments</th>
</tr>
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<tbody>
<tr>
<td>Reminders &amp; simple record keeping</td>
<td>Able to reach patients in real time. Highly reliable operation. Able to store doctor’s dosing instructions. Able to record patient adherence entries.</td>
<td>Smartphone apps, 3G/4G/5G cellular networks and wireless LANs.</td>
<td>Cellular (3G/4G/5G) networks are more suitable for personalized, smart, and contextual reminders.</td>
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<tr>
<td>Integration with electronic health records (EHRs)</td>
<td>Able to securely update or download information from EHRs. Able to detect potential problems in patient consuming the prescribed medications. (patient history, side effects, interaction with other medications, recent advisories, and so on).</td>
<td>Smartphone apps, 4G/5G cellular networks and wireless LANs.</td>
<td>Processing can be performed or assisted by a server.</td>
</tr>
<tr>
<td>Smart medication box and smart pill integration</td>
<td>Able to connect with smart medication boxes, sensors, and dose-dispensing systems. Highly reliable operation.</td>
<td>Smart medication boxes, Bluetooth, RFID, smart pills, smartphone apps, 4G/5G cellular networks and wireless LANs.</td>
<td>Such dose information is more accurate than information recollected and entered by patients.</td>
</tr>
<tr>
<td>Wearable/implantable technology implementation</td>
<td>Able to detect any potential problems in patient consuming the prescribed medications. (patient history, side effects, interaction with other medications, recent advisories, and so on). Able to calculate context-specific dosage based on vital signs.</td>
<td>Bluetooth, RFID, 4G/5G cellular networks and wireless LANs.</td>
<td>IT is still in assistive role, where healthcare professionals can override any actions.</td>
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<tr>
<td>R&amp;D research integration</td>
<td>Able to provide detailed consumption history for analysis. Able to record and transmit vital-sign data with consumption history. Able to anonymize data while maintaining clinical validity. Can make data available to qualified clinicians.</td>
<td>Smartphone apps, tablet computers, 4G/5G cellular networks and wireless LANs.</td>
<td>Processing can be performed or assisted by a server. Both medication adherence and outcomes can be seriously improved.</td>
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11. S. Fischer, “Forecast 2014: This Year Will Be a Good One for Biomedical Engineering—Thanks to Breakthrough Technologies and Unprecedented Funding Opportunities,” *IEEE Pulse*, vol. 5, no. 1, 2014, pp. 18–27.

**Gregory Gimpel** is a clinical assistant professor of computer information systems at Georgia State University. His research focuses on the intersection of emerging technologies, analytics, and digital business transformation. Gimpel has worked for the Massachusetts Institute of Technology Center for Digital Business and headed the team that designed Ball State University’s business analytics major. He received a PhD from Copenhagen Business School and an MRA from the University of Southern California. Contact him at ggimpel@gsu.edu.

**Upkar Varshney** is an associate professor of computer information systems at Georgia State University. His research interests include mobile health, wireless networks, and health IT. Varshney has authored numerous journal and conference papers and serves as a senior editor for IEEE Computer and Decision Support Systems. He received a PhD in computer science and telecom from the University of Missouri–Kansas City. Contact him at uvarshney@gsu.edu.

**Punit Ahluwalia** is an associate professor in the Information Systems Department at the University of Texas–Rio Grande Valley. His research interests include quality of service in wireless networks, mobile transactions, IT-enabled empowerment, and information security. Ahluwalia has authored numerous papers for many prestigious journals and conferences. He received a PhD in computer information systems from Georgia State University. Contact him at punit.ahluwalia@utrgv.edu.