STATE OF THE ART AND SCIENCE
The Future of Smartphones in Health Care
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Smartphones are quickly becoming a nearly ubiquitous technology. In 2009, approximately 64 percent of physicians in the U.S. owned smartphones [1]. Just 1 year later, a separate investigation put smartphone ownership among health care professionals in the U.S. at 81 percent, growing to 91 percent in 2012. Smartphone ownership among European health care professionals grew at an even faster rate, from a lower initial penetration of 44 percent in 2010 to 81 percent by 2012 [2].

Closely associated with mobile technology and equally important for mobile health care are tablet computers, which exhibited an equally impressive climb in usage by physicians from 30 percent in 2011 to 62 percent in 2012 to more than 72 percent in 2013 [3]. The rapid ascendance of the tablet is not surprising, given that 51 percent of health care professionals use tablets for accessing electronic health records (EHRs), the second most frequent use after sending emails [4]. These clear trends towards mobile device adoption, both in general society and within the medical community, have positive implications for patients' health and the patient-clinician relationship.

Out-of-Clinic Use
The first frontier of mobile health care technology is out-of-clinic patient use of software applications (apps) and peripheral hardware that plugs into or attaches to a smartphone or tablet. Already, smartphone-compatible medical devices such as weight scales, blood pressure cuffs, and pulse oximeters are making their way into patients' homes. By providing health information and instructions for use in a user-friendly interface, smartphone-synced devices empower patients to take an active role in their own health. Unlike older generations of at-home monitoring equipment that required manual record keeping, these smartphone devices' associated apps allow patient data to be automatically recorded and stored in personalized profiles that can be transmitted securely to the patient's medical home. They also present that data in comprehensive visual formats such as graphs that convey trends over time and often include explanations of appropriate ranges for a health metric, given patient-specific factors such as age, weight, and sex. By eschewing the need for tedious data collection and putting the emphasis on educating the patient about his or her own health, such apps may ultimately enhance patient engagement.

Currently, there are myriad such medical devices on the market, each of which interfaces with its own app. Looking forward, the next generation of mobile technology needs take into account multiple-device integration and the tech-savvy

patient trying to keeping track of data from different devices. Some apps are already moving in this direction [5-8], for example interfacing with both a scale and a blood pressure monitor in addition to monitoring health and fitness activities, providing back-end cloud-based health information management that can interface with any smartphone medical device [9], or putting forth an all-in-one tool to measure temperature, blood pressure, and blood oxygenation [10]. With one app at the center of a family of devices, patients can centralize their at-home health care.

In addition, smartphone compatibility has put even more powerful medical devices, previously found only in doctor's offices and hospitals, directly into patients' hands. Visual acuity assessment, optic disc visualization (ophthalmoscope), inner ear visualization (otoscope), lung function (spirometer), heart function (ECG), body sound analysis (stethoscope), and even sonography (ultrasound) can all now be conducted using an app or peripheral hardware, and most of these are already—or are on their way to becoming—FDA approved [11]. However, these devices are not meant to replace visits to a clinician. They simply make it easier to collect clinically relevant data, thus allowing clinicians to spend more time analyzing and interpreting data, counseling patients, and developing treatment plans.

In-Clinic Use
As smartphone-enhanced medical devices continue to be integrated into patients' lives at home, the next step is clinical adoption. Early adopters will be clinicians who already use many of the devices and are confident in the capabilities and the accuracy of the technology. Eric Topol, MD, for example, who has twice diagnosed arrhythmias on airplanes using a mobile electrocardiogram (ECG) [12], is a leading supporter of smartphone-based health care. Mobile physicians, such as those in emergency medicine, will find clear value in portable devices that can, for example, capture focused assessment with sonography for trauma (FAST) images and send them through a smartphone to the hospital ahead of the patient for pre-arrival diagnosis by a physician [13].

Primary care clinicians may also find value in using mobile technology in the clinic. One of the biggest challenges with any new device is its potential to distract the clinician and alienate the patient, ultimately emphasizing technology over people. When the clinician becomes too focused on the data collection process, he or she begins to lose the personal connection that lies at the heart of the patient-clinician relationship. For at least two reasons, the smartphone offers the potential to usher in a new era of medical devices that reverses this trend. First, smartphone-based medical devices are typically less invasive and easier to use than their predecessors. For example, a single-channel ECG can be integrated directly into a durable iPhone case. Though a one-lead ECG will of course not provide as comprehensive an assessment of heart function as the twelve-lead ECG, it can quickly and easily perform basic heart monitoring without being cumbersome—ideal for quick screenings or event monitoring. Likewise, plug-and-play blood pressure cuffs connect directly to a smartphone; the clinician does not need to simultaneously manipulate both a stethoscope and sphygmomanometer while trying to speak to the

patient. Instead, the clinician can focus on engaging the patient about his or her health and not be distracted by the data collection process.

Second, the apps of smartphone-based devices typically provide a visual or auditory representation of the collected data that can be shared, allowing the patient to better understand what the doctor is looking at and listening for. For example, when a doctor uses a standard ophthalmoscope to examine a patient's eye, the patient has no idea what the doctor is seeing. With mobile digital imaging and recording apps [14], on the other hand, the doctor can record a snapshot of the patient's optic disc, which can then be shown and explained to the patient and included in the patient's EHR along with the doctor's notes. Similarly, whereas stethoscopes allow only the doctor to hear a patient's body sounds, digital stethoscopes [15] not only record and play the sounds but also present a visual representation of them.

While these smartphone-based clinical tools have much potential, there are clear obstacles to their widespread adoption [16], including potentially disrupted clinical communication, social disengagement, technology failures, and patient harm. In this last category, not only do smartphones and associated devices have the potential to spread nosocomial infections, they may also lead to breached confidentiality. Clinicians must determine whether they should collect and exchange patient data using their own personal devices or adopt devoted clinical devices for such activity. The mobile health industry has indicated its understanding of this privacy issue, so many device manufacturers have prioritized patient data security by integrating HIPAA-compliant communication systems [17].

In summary, smartphone- and tablet-based medical devices and apps have significant potential to affect the patient-clinician relationship and improve the efficiency of the health care system. Moving forward, it will be important for early adopters to address the problems associated with these devices in both the ambulatory and clinical setting and to optimize workflow so the broader clinical and patient communities may adopt them.

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