Mobile Phones to Improve the Practice of Neurology

Neil Busis, MD[a,b,c,*]

KEYWORDS

• Mobile phones • Smartphones • Information technology
• Neurology practice

CASE STUDY: SOLVING A SPELL ON THE SCENE

A young man feels funny and then loses consciousness. His friends record the event with the cameras on their cell phones, documenting left head and eye deviation with left arm posturing. A subsequent electroencephalogram demonstrates a temporal lobe seizure focus.[1]

This case study only hints at the potential for smartphones to revolutionize medical care. As Zeiler and Kaplan,[1] the case authors, state, "One picture is worth a thousand guesses." Often patients cannot accurately describe their neurologic spells and neither can witnesses. Mobile voice and data interchange in the medical information domains of patient data, clinical decision support, and practice management bridges time and space, allowing near instantaneous diagnosis and treatment while at the same time redefining the meaning of "the point of care."[2–4]

This article addresses mobile health care via smartphones. The biggest advances may be expected to come about in developed countries, but this is not the case. A United Nations report describes mobile phones as having the greatest impact in developing countries.[5] Although many developing countries do not have widespread or even dependable broadband Internet access, much of their population has access to cell phones. These devices make it convenient to schedule appointments, receive medical results, and ensure timely alerts and reminders regarding upcoming tests, procedures, and medications.[6,7]

[a] Division of Neurology, Department of Medicine, UPMC Shadyside Hospital, Pittsburgh, PA 15232, USA
[b] Neurodiagnostic Laboratory, UPMC Shadyside Hospital, Pittsburgh, PA 15232, USA
[c] Pittsburgh Neurology Center, 532 South Aiken Avenue, Suite 507, Pittsburgh, PA 15232, USA
* Corresponding author. Division of Neurology, Department of Medicine, UPMC Shadyside Hospital, Pittsburgh, PA 15232.
E-mail address: nab@neuroguide.com

Neurol Clin 28 (2010) 395–410
doi:10.1016/j.ncl.2009.11.001 **neurologic.theclinics.com**
0733-8619/10/$ – see front matter

A disclaimer is in order. Technology articles are out of date as soon as they are written. The emphasis in this article, therefore, is on concepts and principles rather than specific hardware models and software versions.

THE BIG PICTURE—SETTING THE STAGE

Hardware/Network/Software Trends

Several interrelated developments will change how health care is accessed and provided.[8] Computing and communicating devices not only are getting smarter, smaller, faster, and cheaper but also are evolving from fixed to portable, non-networked to networked, wired to wireless, and location- and orientation-agnostic to location- and orientation-aware. We are moving to a world of health information technology literally at our fingertips, available at the point of care in clinical practice.

Mobile Phones

Mobile phones are devices that transmit not only voice messages but also text and multimedia messages (messages composed of text, moving or still pictures, and sounds). Mobile phones can now acquire multimedia with built-in cameras and voice recorders. They are continually gaining computing power.

Computer User Interfaces

Virtually all recent models of desktop and laptop computers employ a graphical user interface controlled by a mouse or some other pointing apparatus. In contrast, most of the successful smaller portable devices have adopted a touch-based interface. Users tap and choose icons, words, and so forth with a stylus or a finger. Recently introduced multitouch (or gesture) interfaces allow users to manipulate the objects on screen by touching two or more places on the screen at once, for example, touching a picture with two fingers and spreading them apart enlarges the picture.[9] This makes the interaction between users and portable devices more intuitive than through the use of a tiny trackball, pointing stick, stylus, and so forth to interact with a display.

Networks

Advances in networks, most notably the ongoing transformation from wired to wireless, have accelerated the mobile computing revolution. Wireless networks can be narrower in range (a Bluetooth personal network, for example) or provide wider coverage (eg, the Internet) than many traditional local wired networks. Many mobile devices use several types and ranges of network interfaces, including satellite channels, cellular networks, Wi–Fi, and Bluetooth.

Cellular wireless networks depend on a series of cells—towers loaded with transmitters—which automatically transfer users' signals as they move from one tower's coverage area to another's. Each cell phone carrier uses proprietary network technology, which, with few exceptions, is incompatible with those of other carriers. It has recently been proposed that all cellular carriers begin sharing the same core network technology to allow devices acquired from one cellular carrier to be used on another carrier's network.

Wi–Fi is a local type of cellular network with a range of approximately 300 feet. Wireless access points broadcast a signal that users' devices pick up. The handoffs are usually not automatic when leaving one Wi–Fi coverage area and entering another; nevertheless, Wi–Fi transmission speeds are faster than on existing cellular networks.

Bluetooth personal networks allow the creation of a short-range personal area network of up to approximately 30 feet in range. For example, Bluetooth can connect a mobile phone to a wireless headset, a car's audio system, or a printer.

Voice over Internet Protocol may greatly increase access to long-distance telecommunications. Voice is translated into data that are transmitted over the Internet rather than through a cell phone carrier's proprietary networks. Users whose devices are equipped with Voice over Internet Protocol applications, such as Skype or Vonage, and who have broadband Internet connections can call similarly equipped devices anywhere in the world without paying cell phone charges.

Global Positioning System and Accelerometers

The Global Positioning System (GPS) relies on location data computed from signals from satellites orbiting the Earth. GPS allows users of appropriately equipped mobile devices to detect their location (actually the location of their device) and broadcast it to others to find nearby attractions and resources (with reviews) and generate directions as a list or in real time, turn-by-turn. If the device is lost or stolen, GPS can help find it. GPS enhances social networking applications by pinpointing friends' locations. A built-in compass adds to the GPS functionality.

Accelerometers inform a device about its orientation in space. Appropriately equipped smartphones can automatically switch from portrait to landscape view when they are rotated. Accelerometers enhance user input options and can be used to control games or other devices. They can even act as an electronic carpenter's level.

Cloud Computing

Cloud computing is an evolution of client-server computing. A client (a computer) is networked (wired or wirelessly) to a larger computer somewhere else (the cloud) in which most of the data and computing power resides.[10] This greatly enhances the information technology capabilities of small, relatively underpowered, computing devices, such as smartphones, because they are now able to offload large amounts of data storage and computations to more capacious and capable machines. The cloud can also be used to back up data on a mobile device. If a device is lost, the backup is simply retrieved from the cloud onto a replacement device. Moreover, the cloud allows synchronization of data among various devices. Users can ensure that desktop, laptop, and mobile devices contain the same contacts, calendar, Web browser bookmarks, and so forth, by synchronizing them with a server located in the cloud.

ABOUT SMARTPHONES

What are Smartphones?

Smartphones represent the convergence of mobile computers and cellular telephones.[11] Carrying around a communication device and a separate mobile computing device is no longer needed. Smartphones are the logical successors of traditional cell phones and personal digital assistants (PDAs), with more capabilities than both, separately or in combination. Just as it became inconceivable to buy a computer without Internet capability, one no longer thinks of buying a mobile computing device or a PDA without network potential. Mobile access to computing power, multimedia communications, the Internet, and individual physical location are in the palms of our hands. Phone numbers are now user-specific not location-specific.

The Smartphone Market

Cell phones are replacing landlines as the preferred method of telephone communication.[12] The percentage of cell phones that are smartphones is relatively low in the world today, but the numbers are rising. In 2008, of the 1.19 billion mobile phones

sold worldwide, 155 million (13%) were smartphones. Experts predict that in 2013, 280 million (20%) of the 1.4 billion phones sold will be smartphones.[13]

Major Smartphone Platforms

Currently, the two major smartphone platforms in the United States[14] are the Apple iPhone (http://www.apple.com/iphone/) and various Research In Motion BlackBerry models (http://www.rim.com/). There are other smartphone platforms with smaller market shares. Palm makes smartphones (Pre and Pixi) based on its new operating system, webOS (http://www.palm.com/). They have phased out their older platform, the Palm OS, a previous market leader. Google provides its Android smartphone operating system for free and various manufacturers are developing devices based on this platform (http://www.android.com/). The Windows mobile platform (http://www.microsoft.com/windowsmobile/) has been around for years but is losing market share to these newer rivals. Nokia (http://www.nokia.com/) is the world leader in smartphones with its Symbian platform (http://www.symbian.org/) but has only a small market share in the United States. There are smartphones based on Linux (http://www.access-company.com/) and other proprietary technologies, although these constitute only a tiny portion of the market.

The Smartphone Ecosystem

Each smartphone lies at the epicenter of its own ecosystem. A smartphone is connected via its cellular or Wi–Fi network to

1. An application store that contains software, which can be loaded on the smartphone
2. The Internet for e-mail and Web access
3. The cloud for synchronization, backup, and, in some cases, more intense data processing.

Smartphones have spawned a robust accessory market. The most popular accessories include wired and wireless headsets and speakers, cases, and wall and car chargers.

Because the different smartphone hardware operating systems are mutually incompatible (except that all are able to access the Web via browsers and e-mail), their ecosystems are all separate. The Apple iPhone ecosystem is the best developed (http://www.apple.com/iphone/apps-for-iphone/ and http://www.apple.com/mobileme/), and others are currently playing catch-up with their own application and accessory stores and with cloud computing systems.

SMARTPHONE APPLICATIONS

Overview of Smartphone Functionality

Smartphones can think, sync, and link. They think by accessing references and databases that reside on smartphones themselves. They sync to other devices and to the cloud. They link to the Internet. Smartphone applications include those that are generally available to the public and those that are specific to a specialty, such as medicine.

There are three sources of applications—those built in by the manufacturer, those downloaded from third parties and then installed by a user, and those accessed via a mobile phone's Web browser.[15] Different manufacturers provide varying numbers and types of built-in applications. Third-party applications can be downloaded for some devices directly from the developers but in some smartphone ecosystems that can be done only via an intermediary. For example, iPhone applications can

only be downloaded and installed (officially, at least) via the iTunes application store. Web-based applications are not installed on the device—they are accessed via an active Internet connection.

Built-in Smartphone Applications

Most smartphones come with many built-in applications. They cover the core functions of smartphones—traditional functions, such as notes, and newer ones, such as GPS.

The primary function, of course, is the telephone. The software not only enables one-to-one voice communication but also allows easily setting up conference calls and voicemail for messages. Some of the newer smartphones feature visual voicemail, which streamlines the process of retrieving messages via the generation of a detailed list on smartphones themselves, thereby obviating calling and listening to a cumbersome audio menu. Messaging is a basic function of smartphones. This includes not only text messages but also multimedia messages, which incorporate still or moving pictures or sound.

In addition to information entered by a device owner, the contact management and calendar applications can include information provided by a user's organization. Some corporate contact and calendar databases reside on the cloud. For example, Microsoft Exchange uses ActiveSync to synchronize frequently updated data on a corporate server with a user's mobile device.

Web and e-mail access are now standard smartphone features. Mobile Web browsers enable users to search, browse, and interact with content formerly available only on desktop and laptop computers. E-mail applications can access individual or private accounts and organizational and corporate ones. With some e-mail protocols, the messages reside on a user's device, but with others, such as Microsoft Exchange, the device only views the mailbox contents—the actual messages are stored on a server somewhere in the cloud.

Notes and to-do lists are holdovers from original PDAs, such as the PalmPilot. Notes are small snippets of text used for references and reminders. To-do lists are useful as reminders of tasks recently assigned and yet to be completed. The more feature-rich smartphones allow notes and to-do lists to be synchronized to the cloud or to a user's desktop or laptop computer.

Multimedia capabilities are becoming incorporated into consumer and corporate smartphones. They allow users to access and acquire music and voice, photographs, and video. With voice recognition, users can say the name of a person or organization or the associated phone number, and the device processes the request and dials the correct number.

Newer smartphones have system-wide indexing and search. A single screen provides a gateway to relevant information in contacts, e-mail, calendars, notes, and so forth.

Location- and orientation-based applications are enabled by GPS and accelerometer capabilities, respectively. Some are built in, such as the map application and photo geotagging on an iPhone.

Add-on Applications for Smartphones

Some add-on applications are useful to a wide variety of users and reside on the device. They can extend built-in functionality—for example, a barcode reader extends the functionality of a built-in camera—or they can add new functionality, such as an electronic wallet. Some applications act as a front end to Web-based services, including search engines, such as Google or Yahoo; social networking sites, such

as Facebook or Twitter; news sites and RSS readers; Wikipedia and other references; and blogs and wikis.

Any Web site can be considered an add-on application because it can contribute functionality that is not built into smartphone software. Some Web sites are friendly to the limited feature set of mobile Web browsers, but some are not, so their utility varies by site and device.

Health Care Applications for Smartphones

There is a rapidly expanding universe of specialized health care applications for users of all the major smartphone platforms. Applications for patients and providers are discussed.

Applications for Patients

Lifestyle applications can help manage weight loss, diet and cooking, and exercise of brain and body. There are many applications for patient information and education, including general references such as Consumer Reports Health (http://www.consumerreports.org/health/) and the Mayo Clinic Health Letter (http://healthletter.mayoclinic.com/). Some are very specific, for example, a list for hikers of the most poisonous snakes. Applications may reside on a device or be accessed via the Web. A good example of the latter is the National Institute of Neurological Disorders and Stroke disease database with direct links to patient support groups (http://www.ninds.nih.gov/disorders/disorder_index.htm).

Smartphones allow patients to communicate with their health care providers by voice, text, and multimedia. In certain circumstances, patients are able to show their health care providers what is going on from a distance, as demonstrated in the case study discussed previously, in which a video of abnormal movements was shown or sent to the patient's neurologist. Communication can also be facilitated through foreign language translators. Patients can access and share personal medical information on smartphones. These include medication, allergy, and problem lists and can include comprehensive personal medical records. Medical social networks and communities, such as the BrainTalk Communities (http://brain.hastypastry.net/forums/), can be developed or accessed via mobile phones. For those patients with substantial neurologic impairments, such as limited mobility, access to virtual communities may greatly expand their horizons and sense of empowerment.[16]

Mobile phones have the potential to enhance the provision of health care around the world, wherever a cell phone infrastructure exists. Even in less developed areas, mobile phones can be used to send and receive test results, alerts, reminders, and advice. For example, text messages can remind patients to take their anti-HIV drugs. Mobile phones can be used for disease management, remote monitoring of symptoms and epidemics,[17] and questionnaires. They can even be used as prosthetics for sensory or cognitive impairments. For example, a smartphone application called Speak it! can transform text into speech.[18] It can give a voice to those who have been rendered voiceless, and can assist those who are sight impaired. Another smartphone application helps compensate for anterograde amnesia in memory-challenged patients.[19]

Applications for Health Care Providers

There is a rich array of applications for health care providers. Some of the most compelling uses rely on built-in core smartphone functions. Many other applications are easily installed. Even more functionality is available if additional infrastructure – hardware or software on desktop or laptop computers–is also installed and utilized.

Physicians and other providers can use smartphones to easily communicate with offices, answering services, colleagues, and patients. Pagers can be replaced by the two-way messaging capabilities.

Reference material and databases are plentiful. Some contain preclinical content, such as anatomic and radiographic atlases, and there are even audio collections with heart sounds. Clinical references cover diagnosis, treatment, practice guidelines, and practice parameters. Mobile versions, reformatted to best fit a mobile device's small screen, exist for several relevant Web sites, including the mobile version of the American Academy of Neurology's Web site (http://m.aan.com).

Users can search and retrieve full text of peer-reviewed medical literature via specially designed applications, such as PubMed On Tap for the iPhone, or via the smartphone's Web browser. Reference management tools are available. Papers for the iPhone, for example, for articles and abstracts saved in portable document format (PDF), has an interface similar to iTunes. There are instructions on how to perform medical procedures, incorporating sound and video. A series of instructional resources on how to perform electromyographic and nerve conduction studies by Dr Joseph Jabre is particularly useful (http://www.teleemg.com). Continuing medical education credits can be achieved over the Web on several free services.

Drug databases contain names of drugs, their indications, dosages, pharmacology, interactions, contraindications, cost, pill identifiers, and so forth. Drug-drug interactions calculated at the point of care are critically important. There are also databases for diagnostic tests that list indications, normal/abnormal values, and how to interpret certain laboratory results.

There are many multifunction clinical calculators, such as the free MedCalc,[20] and more specific ones, such as the National Institutes of Health (NIH) Stroke Scale calculator, for point-of-care stroke documentation and medical decision making. Practice management resources are also available for many smartphone platforms. These include reference materials, searchable databases, and calculators for proper diagnosis (*International Classification of Diseases, Ninth Revision-Clinical Modification [ICD-9-CM]*), evaluation and management, and procedure (*Current Procedural Terminology [CPT]*) coding.

Applications can assist in diagnostic testing. EyePhone, an application for the iPhone, is a visual acuity test optimized for the iPhone screen. Basic telemedicine can be achieved with smartphones by taking pictures or videos and sending them as multimedia messages between patients and providers.

More advanced telemedicine capabilities are possible with appropriate infrastructure.[21,22] A sophisticated camera and electronic medical record system at the point of care could transmit images and data to an offsite physician who is carrying only a smartphone. Access to imaging studies can be done via a smartphone if it is connected to a hospital or organization's digital radiology system. Mobile telephone microscopy is emerging in which the camera of a smartphone is connected to a microscope, and the images of the slides are sent for interpretation to an offsite pathologist. Remote patient monitoring is available for smartphones if they are connected to intensive care unit monitoring devices in a hospital.

Computer-assisted medical decision making is best done when a smartphone is connected to other computers. Patient alerts and reminders, electronic medical records, rounding lists, charge capture, and electronic prescribing are available as stand-alone applications, but functionality is greatly enhanced if a mobile device acts as a client for a hospital or organization's main electronic medical record system.

The same is true for physician quality measure reporting. Under the current model of the Physician Quality Reporting Initiative, providers submit numbers of patients with

a particular diagnosis who received a certain type of treatment or advice. This works best if the patients' diagnoses and treatment have been stored in an electronic medical record. It would be difficult to do this from a smartphone operating in isolation.

The basis of continuous quality improvement is to model, measure, and manage. Another way to say this is plan, study, and act. By closing the feedback loop through the use of data collection at the point of care, smartphones will enable more valid continuous quality improvement projects in medicine.

Tying mobile phone data collection into a remote database permits epidemiologic studies to be performed even in developing countries. Clinical trials are also greatly extended using smartphone-based data collected by patients and providers. Location-specific capabilities enable patient tracking.[23]

Mobile phones are used as remote controls for games and for other electronic devices. It is probably not far off that simple robotic surgery will be controlled by an offsite surgeon using a mobile phone.

Patients often use the same applications that their providers use. Many patients use Epocrates, the National Institute of Neurological Disorders and Stroke Web site, and PubMed. It is useful to access these resources from time to time and try to see them from a patient's point of view (**Figs. 1** and **2**).

SMARTPHONES AND PERSONAL DIGITAL ASSISTANTS IN MEDICINE—THE LITERATURE

Information technology can improve health care.[24] Case studies[25,26] and peer-reviewed medical literature[27] attest to the usefulness of smartphones and PDAs in medicine. In community hospitals and ambulatory clinics without wireless networks, real-time access to current medical literature may be achieved through applications on smartphones. Immediate availability of reliable and updated information obtained from authoritative sources on the Web makes evidence-based practice in community hospitals a reality.

An up-to-date bibliography is always available via a PubMed search (http://www.pubmed.gov) using the phrase, ''Cellular Phone''[Mesh]. As of October 25, 2009, 1624 relevant articles were retrieved, 105 of them reviews. One recent study concluded, ''enhancing standard care with reminders, disease monitoring and management, and education through cell phone voice and short message service can help improve health outcomes and care processes have implications for both patients and providers.''[28]

CHALLENGES AND SHORTCOMINGS

Although smartphones are promising devices and getting better almost every week, they have challenges and shortcomings. Interoperability is problematic for developers and end users. Platform-specific applications (those loaded directly onto a smartphone) are faster and may access more specific features of smartphones, but they require more resources and development time.[29] Small developers have to decide how many platforms they will support. The potential solution is to make well-designed, Web-based applications that are platform neutral. Their functionality is more limited, however, due to their inability to access some of the key built-in features of specific devices that make smartphones such a compelling platform. For example, network-based applications may be impeded by patchy, uncertain, or slow connectivity.

Data input is often clumsy and error prone.[30] Some smartphones have physical keyboards that are small and cramped, and typing on them is difficult. Some have virtual keyboards. Virtual keyboards can be reformatted for portrait and landscape modes and different keys can be available for different applications or different

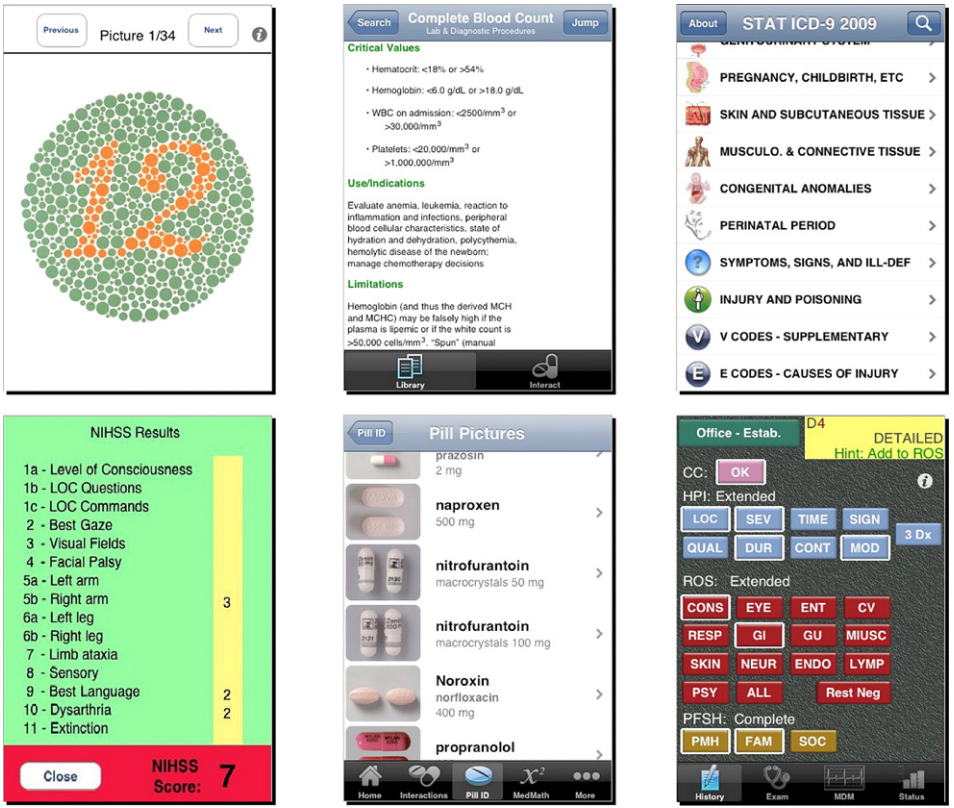

Fig. 1. Neurology applications for smartphones. (*Top row, left to right*) Test for color vision, database of laboratory tests, and *ICD-9-CM* (diagnosis codes) database. (*Bottom row, left to right*) NIH Stroke Scale calculator, drug database, and evaluation and management CPT code calculator. These examples are for the iPhone. Similar applications may be available for other smartphones.

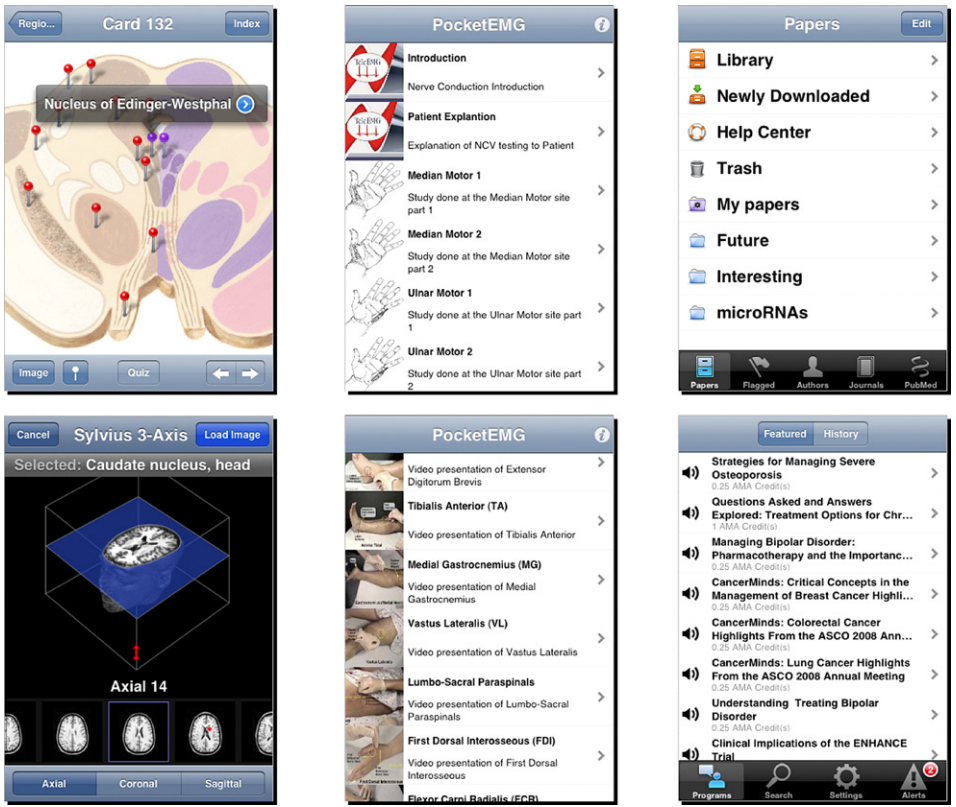

Fig. 2. More neurology applications for smartphones. (*Top row, left to right*) Neuroanatomy atlas, nerve conduction study instructions with illustrative videos, and reference manager (indexes and accesses PDF files of collected references). (*Bottom row, left to right*) Neuroradiology atlas, electromyographic instructions with illustrative videos, and free continuing medical education application. These examples are for the iPhone. Similar applications may be available for other smartphones.

languages, but there is no tactile feedback. Typing is slower on a virtual keyboard than on a physical keyboard, although many users do not mind or adjust to it within a short time.

Battery life can be limiting. Many smartphones have only a few hours of active battery life, barely enough to get through a full business day without recharging. Although battery life can be extended by turning off some of the features of the smartphone (for instance, GPS location, Wi–Fi, or Bluetooth), that partially defeats the intended purpose of smartphones.

Do smartphones actually access the real Web? The answer is sometimes yes and sometimes no. The small screen can be an impediment to users, because it is like looking at the Internet through a keyhole. Although almost all Web sites can be visited, to visualize many at a font size that is reasonable, a fair amount of horizontal and vertical scrolling is required, which may become tedious. One particularly troublesome development is the increasing use of plug-ins, such as Adobe Flash, for Web sites. Currently Flash solutions are absent or not completely satisfactory for smartphone platforms. Web sites without alternative non-Flash versions do not have full functionality on smartphones. The solution is to visit only Web sites optimized for mobile phone Web browsers, but the tradeoff is often a loss of functionality.

Privacy is concerning. Not only are there Health Insurance Portability and Accountability Act concerns about patient information on mobile devices, but also users of the devices may object to certain smartphone features. Carriers could monitor how devices are used on their networks and potentially intercept e-mail, Web transmissions, and so forth. Location-based services could monitor users' locations without their knowledge or approval.

Security remains a challenge with smartphones. What to do about loss or theft? Although Microsoft Exchange–based systems have Remote Wipe and Apple's MobileMe has introduced this functionality to their smartphones, there are ways to circumvent this safeguard.

Cloud computing has its downside. If all user data reside on remote servers and they fail without adequate backups, then important information can be irretrievably lost.[31]

What about viruses and worms (malware) for smartphones? These will probably become an increasing threat as more hackers devote their attention to these platforms. This is one instance in which the multiplicity of operating systems is actually a good thing. Because no smartphone maker controls the vast majority of devices (unlike the Windows-dominated personal computer [PC] world), it would be difficult for malware to inflict as great a negative impact on smartphones as it can on PCs. Antivirus software makers are starting to explore products for smartphones due to the anticipated threat.

HEALTH PROBLEMS (POTENTIAL AND PROVED) AND UNINTENDED CONSEQUENCES

All technologic advances have negative aspects, and many cannot be predicted or anticipated. Edward Tenner terms this "the revenge of technology."[32] The potential adverse health consequences of cell phones are increasingly recognized.[33]

The biggest unsettled health-related question is whether or not cell phones cause cancer.[34–36] Although this has not been proved despite much investigation, absence of evidence is not evidence of absence. Some, but not all, authorities opine that further studies are needed.

Minor medical maladies are associated with overuse of smartphones. There is the so-called BlackBerry thumb, from overuse of the thumb-based keyboard.[37] There

are scalp and ear dysesthesias reported from holding a cell phone too close to the ear during prolonged talking.[38]

More serious are the decreased attention and difficulties with multitasking inherent in having a conversation (voice or data) on a cell phone while doing something else important.[39,40] Talking or texting on cell phones while walking or driving leads to more accidents.[41] Hands-free conversations are shown no less distracting than holding a device to the ear.[42] State and federal lawmakers are beginning to prohibit certain cell phone uses while driving.[43]

Cell phones may cause stress when users are always available and on call. Users may become addicted to the Internet or to their devices (the so-called crackberry phenomenon).[44] Cell phones can sometimes serve as vectors of infection, just as neckties are.[45] Prolonged cell phone conversations can potentially have adverse electromagnetic[46] and thermal effects on central and peripheral nervous tissue.[47] Loud sounds through a receiver can cause hearing loss; this is more likely to occur from listening to music than from conversations.[48] Finally, there are concerns about sterility caused by cell phones, which is currently under investigation.[49]

There are potential problems with the software and hardware. The old adage, ''garbage in–garbage out,'' applies to medical software and any other software. Users entering the wrong data leads to wrong decisions. More perniciously, medical software deficiencies or bugs may give erroneous results. A reported software bug caused a patient to get the wrong dose during radiation therapy with fatal consequences.[50]

Cell phones can cause electrical interference with other medical devices.[51,52] These can be in or on a patient (for example, a pacemaker or a ventriculoperitoneal shunt valve) or around or connected to a patient, such as a monitor, respirator, and so forth. The available literature demonstrates that different combinations of cell phones and devices have different degrees of electrical interference ranging from none to serious. As cell phones become more ubiquitous, manufacturers of cell phones and medical equipment will need to electrically isolate these devices from one another. When in doubt, ask the information technology personnel at a hospital or organization to test the devices to see if they are compatible before allowing them to be used together.

WHAT DEVICE AND APPLICATIONS SHOULD YOU GET?

The answer depends on what problems you want to solve.[53,54] What do you want to sync and link to? What are your e-mail habits? What are your favorite applications? What carriers and networks work best in your area? What can you afford? What does your institution or organization mainly use? What does your institution or organization support? Are you willing to go it alone to use a device that is not supported by your information technology staff?

Currently, the iPhone and BlackBerry platforms are most popular among physicians.[55] The abundance of medical applications favors increasing popularity of the iPhone in the future.[56]

WHERE DO WE GO FROM HERE?

Extrapolating from current trends, smartphones potentially can lead to pervasive computing, with these devices serving as the ''remote control for your life.''[57,58]

It is a safe bet that there will be smarter, smaller, faster, and cheaper devices and faster, more widespread networks that will allow seamless carrier conversions and carrier interoperability. As long as the applications are allowed, there may be liberation from the hegemony of the carriers by allowing users to avoid cellular networks with Voice over Internet Protocol.

More convergence lies ahead. Smartphones are becoming sufficiently capable that they can replace desktops and laptops for many applications. In some small businesses, networks of smartphones may replace landline telephones and PBX systems. There will be phone number convergence. Google Voice and related services will intercept messages from multiple phone numbers and assign them to a single new number. There should be better integration between the users' contacts and activities, especially by location-based services.

There should be better Internet-based applications; better ability to download, upload, and sync; and backup to and from the cloud. There should be better integration with social networking services, location-based services, other digital health care applications and platforms, and virtual communities. There should be smarter alerts and reminders via background patient-monitoring applications.

We hope for better battery life and better displays—some may be projected or some may be flexible and able to be rolled up or folded out. There may be better input with improved voice recognition and perhaps even keyboards projected onto larger spaces. There may be better accessibility for the visually and hearing impaired. There may be better security, including biometric logons (for example, using fingerprints).

We cannot predict future disruptive technologies or economic circumstances. As the saying goes, ''the only guaranteed part of life is change.'' Anticipate the unanticipated—that one or more unexpected devices or applications will have a major impact on the world of mobile devices in the not-so-distant future.

SUMMARY

Smartphones make mobile computing at the point of care practical. Smartphones can think, sync, and link. Built-in and user-installed applications facilitate communications between neurologists and their medical colleagues and patients and augment data acquisition and processing in the core medical information domains of patient data, clinical decision support, and practice management. Mobile telemedicine is becoming practical in certain scenarios. Smartphones can improve neurologic diagnosis and treatment, teaching, and research. Patients also can benefit from smartphone technology. In addition to enhanced communication, patient education, and social networking, these devices can promote healthy lifestyles, preventive medicine, and compliance and even serve as monitoring and prosthetic devices.

REFERENCES

1. Zeiler SR, Kaplan PW. Our digital world: camera phones and the diagnosis of a seizure. Lancet 2009;373(9681):2136.
2. mHealth Initiative Vision. The mobilization of healthcare. Available at: http://mhealthinitiative.org/. Accessed September 20, 2009.
3. Bhanoo SN. New tool in the MD's bag: a smartphone 2009. The Washington Post. Available at: http://www.washingtonpost.com/wp-dyn/content/article/2009/05/18/AR2009051802234.html. Accessed September 20, 2009.
4. mHealth. Wikipedia. Available at: http://en.wikipedia.org/wiki/MHealth. Accessed September 20, 2009.
5. Vital Wave Consulting. mHealth for development: the opportunity of mobile technology for healthcare in the developing world. Washington, DC/Berkshire (UK): UN Foundation-Vodafone Foundation Partnership; 2009. Available at: http://www.unfoundation.org/press-center/publications/mhealth-for-development-mobile-technology-for-healthcare.html. Accessed September 20, 2009.

6. Vaitheeswaran V. Medicine goes digital—a special report on healthcare and technology. The Economist 2009. Available at: http://www.economist.com/specialReports/showsurvey.cfm?issue=20090418. Accessed September 20, 2009.
7. Denison DC. Using cellphones to change the world. Boston Globe 2009. Available at: http://www.boston.com/business/technology/articles/2009/10/14/mit_program_looks_at_ways_to_change_the_world_using_cellphones/. Accessed October 25, 2009.
8. Snyder S. The new world of wireless: how to compete in the 4g revolution. Upper Saddle River (NJ): Wharton School Publishing; 2009.
9. Ricknas M. Gestures set to shake up mobile user interfaces. Macworld (UK); 2009. Available at: http://www.macworld.co.uk/digitallifestyle/news/index.cfm?RSS&NewsID=27104. Accessed September 20, 2009.
10. Cloud computing in plain English. rPath. Available at: http://www.rpath.com/corp/cloudinenglish. Accessed September 20, 2009.
11. Bertman J. Tech 101: a new generation of smartphones. MDNG Neurology 2009; 11(5):26.
12. America loses its landlines—cutting the cord. The Economist 2009;392(8644):55–6.
13. Hempel J. How blackberry does it. Fortune 2009;160(4):92–100.
14. AdMob Mobile Metrics. Metrics report 2009. Available at: http://metrics.admob.com/. Accessed September 20, 2009.
15. Fling B. Mobile design and development. Sebasopol (CA): O'Reilly Media, Inc; 2009.
16. Sarasohn-Kahn J. The wisdom of patients: health care meets online social media. California HealtHCare Foundation 2008. Available at: http://www.chcf.org/topics/chronicdisease/index.cfm?itemID=133631. Accessed September 20, 2009.
17. Golijan R. Healthmap app will tell you how diseased your neighborhood is. Gizmodo. Available at: http://gizmodo.com/5350585/healthmap-app-will-tell-you-how-diseased-your-neighborhood-is; 2009. Accessed September 20, 2009.
18. Vance A. Insurers fight speech-impairment remedy. The New York Times Online 2009. Available at: http://www.nytimes.com/2009/09/15/technology/15speech.html?scp=1&sq=speech-impaired&st=cse. Accessed September 20, 2009.
19. Svoboda E, Richards B. Compensating for anterograde amnesia: a new training method that capitalizes on emerging smartphone technologies. J Int Neuropsychol Soc 2009;15(4):629–38.
20. Tschopp M, Lovis C, Geissbuhler A. Understanding usage patterns of handheld computers in clinical practice. Proc AMIA Symp 2002;806–9.
21. Doty CA. Delivering care anytime, anywhere: telehealth alters the medical ecosystem. California HealtHCare Foundation; 2008. Available at: http://www.chcf.org/topics/view.cfm?itemID=133787. Accessed September 20, 2009.
22. Schwamm LH, Holloway RG, Amarenco P, et al. A review of the evidence for the use of telemedicine within stroke systems of care: a scientific statement from the American Heart Association/American Stroke Association. Stroke 2009;40(7): 2616–34.
23. Kwok R. Personal technology: phoning in data. Nature 2009;458(7241):959–61.
24. Amarasingham R, Plantinga L, Diener-West M, et al. Clinical information technologies and inpatient outcomes: a multiple hospital study. Arch Intern Med 2009; 169(2):108–14.
25. BlackBerry Case Study. Hospital sees blackberry smartphones as a way to improve patient care and save lives. research in motion limited. Available at: http://na.blackberry.com/eng/newsroom/success/Trillium_HealthCentre.pdf. Accessed September 20, 2009.

26. BlackBerry. Revitalizing healthcare delivery with mobile communications. Research In Motion Limited; 2007. Available at: http://na.blackberry.com/eng/campaign/healthcarecampaign/smartphone_benefits.pdf. Accessed September 20, 2009.
27. Leon SA, Fontelo P, Green L, et al. Evidence-based medicine among internal medicine residents in a community hospital program using smart phones. BMC Med Inform Decis Mak 2007;7:5.
28. Krishna S, Boren SA, Balas EA. Healthcare via cell phones: a systematic review. Telemed J E Health 2009;15(3):231–40.
29. Krill P. Smartphones: a tower of babel for developers. Macworld; 2009. Available at: http://www.macworld.com/article/142576/2009/09/smartphone_development.html. Accessed September 20, 2009.
30. Haller G, Haller DM, Courvoisier DS, et al. Handheld vs. laptop computers for electronic data collection in clinical research: a crossover randomized trial. J Am Med Inform Assoc 2009;16(5):651–9.
31. Sarrel MD. The darker side of cloud computing. Available at: PCMag.com 2009; http://www.pcmag.com/article2/0,00.asp,2817,2330904. Accessed September 20, 2009.
32. Tenner E. Why things bite back: technology and the revenge of unintended consequences. New York (NY): Vintage Books; 1997.
33. Kharif O. Is cell-phone safety assured? or merely ignored? Bus Week 2009. Available at: http://www.businessweek.com/technology/content/sep2009/tc20090921_950531.htm. Accessed October 25, 2009.
34. Kundi M. The controversy about a possible relationship between mobile phone use and cancer. Environ Health Perspect 2009;117(3):316–24.
35. Lahkola A, Auvinen A, Raitanen J, et al. Mobile phone use and risk of glioma in 5 North European countries. Int J Cancer 2007;120(8):1769–75.
36. No link between mobile phone use and increased risk of glioma. Nat Clin Pract Neurol 2007;3:303.
37. Rx for BlackBerry thumb. Consum Rep 2009;74(1):12.
38. Westerman R, Hocking B. Diseases of modern living: neurological changes associated with mobile phones and radiofrequency radiation in humans. Neurosci Lett 2004;361(1–3):13–6.
39. Goodman MJ, Barker JA, Monk CA. A bibliography of research related to the use of wireless communications devices from vehicles. National highway traffic safety administration 2005. Available at: http://www.nhtsa.dot.gov/staticfiles/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/Driver%20Distraction/Wireless_Device_Biblio2k5.pdf. Accessed September 20, 2009.
40. Anderson J. Neurology study: brain too slow for cell phone use while driving. Ergonomics Today 2007. Available at: http://www.ergoweb.com/news/detail.cfm?id=1694. Accessed September 20, 2009.
41. Richtel M. U.S. withheld data on risks of distracted driving. New York Times Online 2009. Available at: http://www.nytimes.com/2009/07/21/technology/21distracted.html. Accessed September 20, 2009.
42. Ishigami Y, Klein RM. Is a hands-free phone safer than a handheld phone? J Safety Res 2009;40(2):157–64.
43. Hafner K. Texting may be taking a toll. New York Times Online 2009. Available at: http://www.nytimes.com/2009/05/26/health/26teen.html. Accessed September 20, 2009.
44. Carbonell X, Guardiola E, Beranuy M, et al. A bibliometric analysis of the scientific literature on Internet, video games, and cell phone addiction. J Med Libr Assoc 2009;97(2):102–7.

45. Brady RR, Verran J, Damani NN, et al. Review of mobile communication devices as potential reservoirs of nosocomial pathogens. J Hosp Infect 2009;71(4): 295–300.
46. Ferreri F, Curcio G, Pasqualetti P, et al. Mobile phone emissions and human brain excitability. Ann Neurol 2006;60(2):188–96.
47. Acar GO, Yener HM, Savrun FK, et al. Thermal effects of mobile phones on facial nerves and surrounding soft tissue. Laryngoscope 2009;119(3):559–62.
48. Kumar A, Mathew K, Alexander SA, et al. Output sound pressure levels of personal music systems and their effect on hearing. Noise Health 2009;11(44): 132–40.
49. Makker K, Varghese A, Desai NR, et al. Cell phones: modern man's nemesis? Reprod Biomed Online 2009;18(1):148–57.
50. Attalla EM, Lotayef MM, Khalil EM, et al. Overdose problem associated with treatment planning software for high energy photons in response of Panama's accident. J Egypt Natl Canc Inst 2007;19(2):114–20.
51. van Lieshout EJ, van der Veer SN, Hensbroek R, et al. Interference by new-generation mobile phones on critical care medical equipment. Crit Care 2007;11(5): R98.
52. Tri JL, Severson RP, Hyberger LK, et al. Use of cellular telephones in the hospital environment. Mayo Clin Proc 2007;82(3):282–5.
53. Helmreich D, Doriot P. CFI Group Smartphone Satisfaction Study 2009. CFI Group 2009. Available at: http://www.cfigroup.com/resources/whitepapers_register.asp?wp=41. Accessed October 25, 2009.
54. Halamka JD. The iPhone is what I want, the Blackberry is what I need. Life as a Healthcare CIO 2008. Available at: http://geekdoctor.blogspot.com/2008/08/iphone-is-what-i-want-blackberry-is.html. Accessed September 20, 2009.
55. Elmer-DeWitt P. Six out of 10 doctors prefer iPhones. CNNMoney.com 2009. Available at: http://brainstormtech.blogs.fortune.cnn.com/2009/08/04/six-out-of-10-doctors-prefer-iphones/. Accessed September 20, 2009.
56. Tharp T. Are iPhones or Blackberrys better for doctors and medical students? KevinMD.com 2009. Available at: http://www.kevinmd.com/blog/2009/09/iphones-blackberrys-doctors-medical-students.html. Accessed October 25, 2009.
57. Nadel B. Mobile tech 2010: trends to change our lives. InfoWorld 2009. Available at: http://www.infoworld.com/d/networking/mobile-tech-2010-trends-change-our-lives-691. Accessed September 20, 2009.
58. Rabinowitz E. When will healthcare go mobile? MDNG Neurology 2009;11(5): 16–8.