Special Article

Mobile Medical Computing Driven by the Complexity of Neurologic Diagnosis

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ABSTRACT

Medical computing has been split between palm-sized computers optimized for mobility and desktop computers optimized for capability. This split was due to technology too immature to deliver both mobility and capability in the same computer and the lack of medical software that demanded both mobility and capability. Advances in hardware and software are ushering in an era in which fully capable computers will be available ubiquitously. As a result, medical practice, education and publishing will change. Medical practice will be improved by the use of software that not only assists with diagnosis but can do so at the bedside, where the doctor can act immediately upon suggestions such as useful findings to check. Medical education will shift away from a focus on details of unusual diseases and toward a focus on skills of physical examination and using computerized tools. Medical publishing, in contrast, will shift toward greater detail: it will be increasingly important to quantitate the frequency of findings in diseases and their time course since such information can have a major impact clinically when added to decision support software. (*J Child Neurol* 2006;21:595–599; DOI 10.2310/7010.2006.00155).

Medical computing has been split into two varieties: simple programs that run on palm-sized devices and sophisticated programs that run on desktop computers. The reason for the split is that sophisticated programs (such as electronic health records and Web browsers) require full computers, whereas simple tasks, such as checking laboratory tests or writing

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prescriptions, can be done on mobile pocket-sized computers, which have been very useful for doctors who move around much in the course of their day.

The problem with the split is that there are drawbacks to dividing information among several systems that are loosely connected and poorly synchronized. Well-organized people know that it is better to keep information on one system and have it available ubiquitously.

The split between sophisticated computing and mobile computing is now being overcome for reasons of both supply and demand. Supply is improving because it is getting easier to make full computers available ubiquitously. Demand is increasing because sophisticated new software is appearing with advantages important enough to want full computers available ubiquitously.

One way of making full computers available ubiquitously is to install a large number of desktop computers in all patient areas and meeting rooms. Another approach, just becoming possible, is to allow each doctor to carry around one of the new generation of full computers that fit in a white coat pocket and use wireless networking.

This article discusses the implications of ubiquitous medical computing for medical practice, education, and publishing. Although the examples will focus on the mobility approach to ubiquitous computing, similar conclusions will result if ubiquitous computing occurs through deployment of a large number of desktop computers or docks with hardwired network access. The hardwired approach might be the best solution for hospitals that have difficulty with the security issues inherent in allowing doctors to use the same computer for wireless network access both inside and outside the hospital.

Although the move to ubiquitous computing using full computers is driven by many factors, this article focuses on the factors of most interest to child neurologists, such as the desire to run sophisticated software at the bedside and the preference of patients for doctors writing on a computer instead of typing on a keyboard during an interview. The more general advantages of full computers, such as universal familiarity with full computers, the desire for larger screens than those available on palm-sized devices, and the need to access Web sites not optimized for palm-sized devices are very important, but they are beyond the scope of this article.

NEED FOR CAPABLE COMPUTING AT THE BEDSIDE

Child neurologists are among the groups of doctors dealing with the greatest complexity of diagnoses, needing to consider a huge number of diseases that have many overlapping findings. For child neurologists, diagnostic decision support software is a core example of software that can help with a difficult part of their practice.

I first focused on the capability/mobility tradeoff because of our *SimulConsult Neurological Syndromes* diagnostic software (SimulConsult Inc., Chestnut Hill, MA).[1] The software takes a set of findings and suggests a differential diagnosis among the more than 1000 neurologic syndromes. The original vision for such software was that a doctor would use it on a desktop computer in an office.

The advantage of mobile computing became obvious when we added a feature to analyze the differential diagnosis and identify the findings that would be most useful in distinguishing among the diseases in the differential diagnosis. When the differential diagnosis includes many unfamiliar diseases, such a “useful findings” feature is very helpful, highlighting pertinent positive and pertinent negative findings to be sure to check. The feature is particularly important when it suggests findings that are not part of a routine neurologic examination. This ability to obtain suggestions of useful findings to check while the patient is still there makes the case in a very concrete way for using computers that are both capable and mobile.

This need for both mobility and capability intrigued the mobility group at Intel Corporation (Santa Clara, CA), which provided us with a Tablet PC for the 2004 Child Neurology Society meeting. The Tablet PC uses a special version of Microsoft *Windows* that adds the capability for pen input and handwriting recognition.[2] Tablet PCs have been popular among physicians, who can add drawings to an electronic health record, and they are also well received by patients, who feel comfortable with doctors writing on a computer but do not feel comfortable with a doctor typing while talking to them.

Intel provided us with a standard-sized Tablet PC, the size of a regular notebook computer. Their idea was that doctors would carry around one of these devices. At the Child Neurology Society meeting, I found that the Tablet PC was great for doing demonstrations while talking to someone in the next seat or standing nearby, but virtually every doctor told me the same thing about the usefulness of such a computer: they would not carry around a computer that does not fit in a pocket; they consider such a computer to be capable, but they do not consider it to be truly mobile unless it fits in their pocket.

I was not surprised at the reaction; indeed, I had been making the case for smaller tablets to senior people in the computer industry since the very day that Microsoft unveiled the *Windows XP Tablet PC Edition* in November 2002. I was able to share the consensus from the Child Neurology Society meeting about mobile Tablet PCs with leaders in the computer hardware and software industry. The message got through, and a chief executive officer who received my account from the 2004 Child Neurology Society meeting personally ensured that we had one of the first white coat pocket–sized Tablet PCs in time for the 2005 meeting.

Since 2005, there have been a flurry of releases of Tablet PCs that fit in a white coat pocket. Such mobile computers provide a new way to implement ubiquitous computing and have the potential to change the way we practice, learn about, and publish about medicine.

DIAGNOSIS BEFORE COMPUTERS

When I was a medical student in the early 1980s, the old-time clinicians teaching us how to do a neurologic examination told us that taking a good history and doing a good neurologic examination was far more important than remembering the details of many neurologic diseases. I did not quite believe that, but it was a cheery theme for physical diagnosis sessions. Similarly, when I first heard of Harvard Medical School’s case-based education initiative, my first reaction was that they were a bit naive; one needed an intensive grounding of knowledge about individual neurologic diseases. However, as one of those who got into medical school on the basis of scientific skills rather than a memory for facts, there was a certain appeal to the notion that one could get by with skills and look up some knowledge.

Residency is a great time for checking how expectations match up with reality. One day, I was called by a hospital-based pediatrician to see an 8-month-old boy with split sutures who was presumed to have a brain tumor. Although the baby was not in great spirits, I did a thorough neurologic examination and noted kyphosis of the spine in addition to the macrocephaly. I did not know what disease he had, but doing a thorough neurologic examination shifted my thinking from brain tumors to inherited diseases. The mother related that both the kyphosis and the macrocephaly were noticed by their local pediatrician at the 6-month checkup, with onset shortly before.

I stumbled around before arriving at what in retrospect was the overwhelmingly likely diagnosis. I looked in the boy's eyes (how could one not do so for a patient with split sutures?) and noted corneal clouding. This was enough to aim my focus on storage diseases. To give a good differential diagnosis, however, I would have needed to immerse myself for a while in a textbook and go through many possibilities. Instead, the radiologists got wind of the case, and we soon demonstrated the bony abnormalities that clinched the diagnosis of Hurler syndrome.

The old-time clinicians had been right that a good history and physical examination were crucial to making the diagnosis, but clearly having noticed kyphosis and macrocephaly was not enough for the local pediatrician to realize the seriousness of the situation (the patient would have died soon if he had not received an emergency shunt for hydrocephalus). As a research-oriented physician, I resolved to work on approaches to diagnosis that were more approachable than skimming through an entire textbook.

Using this case of Hurler syndrome, I illustrate how different clinical practice, medical education, and medical publishing will be in an era in which we can count on ubiquitous computing with capable computers.

CLINICAL PRACTICE: USING UBIQUITOUS COMPUTING TO HELP WITH DIAGNOSIS

While seeing this patient at the 6-month visit, the local pediatrician knew something was wrong and told the mother to keep an eye on the findings. Today, any medical professional who has registered on-line[3] to use our *SimulConsult Neurological Syndromes* software could pull a mobile computer out of a white coat pocket and, using the software, put the information together better than any of us did during my residency.

Entering an 8-month-old patient with recent onset of kyphosis gives a differential diagnosis with many diagnostic possibilities (Figure 1).

Clicking the "Add useful findings" button gives the instant advice that makes the argument for mobile computing at the bedside: a number of findings are displayed, ranked by their usefulness in changing the differential diagnosis (Figure 2, center). High in the ranking is macrocephaly, a finding known to be present in this patient. Macrocephaly is present in so many normal babies that it is easy to imagine a general pediatrician taking a wait-and-see approach to a large head, but the fact that

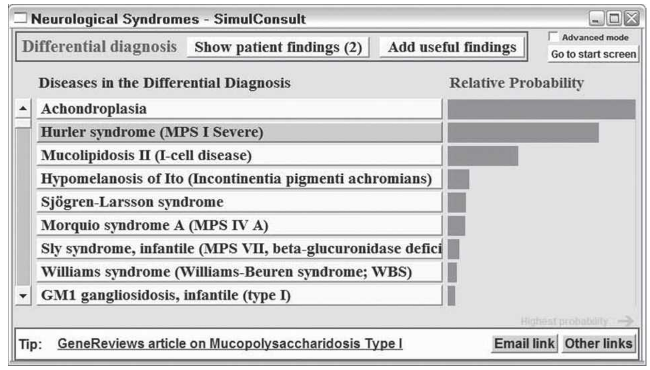

Figure 1. *SimulConsult Neurological Syndromes* display after entering a 8-month-old patient who has two findings: kyphosis with onset at 6 months and being alive at 8 months. A list of diseases in the differential diagnosis is displayed, with bars indicating relative probabilities. Hurler syndrome has been clicked, resulting in a tip with a hyperlink to a review article.

macrocephaly is high on a list of useful findings for this patient with kyphosis suggests that macrocephaly should not be dismissed in this case as an incidental observation. Specifying that macrocephaly was present from birth (by clicking on the drop-down control to the left of "Macrocephaly") pushes the differential diagnosis toward achondroplasia (not shown here but shown in an on-line demonstration video[4]; the case is also available at <http://www.simulconsult.com/neurologicalsyndromes/edu/case_2/> in a form that allows one to click into the diagnostic software). However, specifying onset at about 6 months, as was known for this patient, pushes the differential diagnosis toward Hurler syndrome (see Figure 2, left).

Clicking the "Refresh" button (see Figure 2) results in a new list of useful findings (Figure 3) based on the new differential diagnosis. This new list of useful findings ranks corneal clouding highly among findings useful to check. Entering corneal clouding as present makes the probability of Hurler syndrome more dominant (see Figure 3).

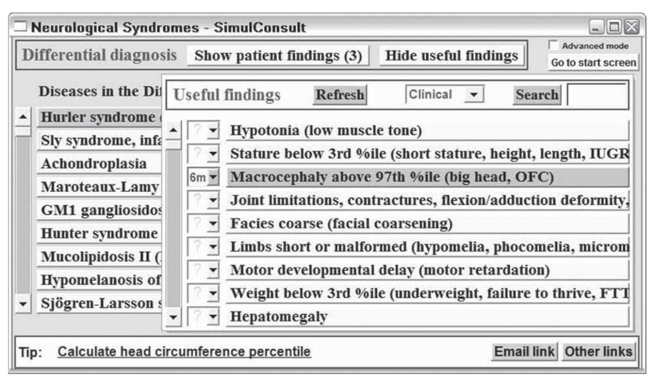

Figure 2. *SimulConsult Neurological Syndromes* display after adding macrocephaly to the profile of an 8-month-old patient with kyphosis. The updated differential diagnosis is displayed at left. The center of the screen shows a list of findings deemed useful according to the ability of the finding to change the differential diagnosis. Macrocephaly with onset around 6 months of age has been entered, changing the differential diagnosis from that in Figure 1 and offering a tip with a hyperlink to a program calculating the head circumference percentile from the measurement.

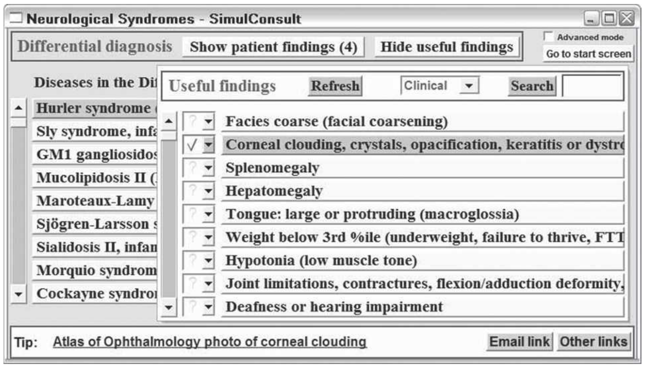

Figure 3. *SimulConsult Neurological Syndromes* display after adding corneal clouding to the profile of an 8-month-old patient with kyphosis and macrocephaly. The age at onset of corneal clouding is not specified because the onset is unknown and might have been far before 8 months. Clicking on ''Corneal clouding'' also offers a tip with a hyperlink to photographs showing corneal clouding.

Using the drop-down "Clinical" control near the top of the screen, one could reduce the default weighting against costly tests, leading to a display showing various tests, including the bone radiograph that we did as an emergency when the patient was 8 months of age. Also ranked high in usefulness was the alpha-iduronidase test that the local pediatrician should have ordered at 6 months (not shown, but it appears in the on-line demonstration video[4]).

Comparing how we approached this patient years ago with how we could approach this patient today makes a powerful case for computing that is both mobile and capable. The computations done by the software are clearly a task for a full computer; assessing more than 1000 findings in more than 1000 diseases would strain the computational power of a palm-sized device, and fitting the information on Figures 2 and 3 onto a tiny screen would be difficult. This example also underscores the benefits of a mobile computer: having suggestions of useful findings is a huge help at the bedside, helping the doctor move back and forth between useful findings and the differential diagnosis. Although the software can be run on regular desktop Windows, Macintosh, and Unix computers, using it on a mobile computer with the patient in the same room allows the doctor to make use of suggestions about findings that are useful to check.

Working on a high-technology approach of diagnostic software has brought me around to agreeing with the old-time clinicians about the paramount importance of doing a good physical examination. The focus on eliciting findings might have been an oversimplification decades ago, but now it is becoming true because of ubiquitous computing. Ubiquitous computing has broad implications, not only for the process of diagnosis but also for how we should be teaching the process of diagnosis.

MEDICAL EDUCATION: UBIQUITOUS COMPUTING AND CASE-BASED EDUCATION

At a time when I was still skeptical about case-based education, Barry Kosofsky and C.J. Malanga asked for help implementing a case-based education initiative they were planning for Massachusetts General Hospital, inspired by a move toward case-based education being considered by the Child Neurology Society. The idea was to pool educational cases nationally and have residents work through the cases on the Web as part of their training. I explained that making Web pages was quite easy, but they insisted on an approach that did not require residents to use a Web page editor. After much brainstorming, it occurred to us that once someone had entered a case into our diagnostic software, the program had all of the information needed to generate a case description as a list of findings and could do so automatically when the resident pressed a "Publish" button. The Web pages displayed the list of findings and a hyperlink so that one could click into the software with all of the pertinent positive and negative findings of the case entered, helping a group of doctors work through a case in a didactic session.

We began collecting cases in this way but became intrigued that a "blog" format would provide cases that were more readable as narratives. Using quotations from newspaper stories and case reports from disease foundation Web sites, we used hyperlinks that jump right into the diagnostic software to create a "cases blog" with very readable educational cases.[5] Beginning with some cases written by Phillip Pearl, we are also starting to do more traditional case narratives for resident education in which the answer is not disclosed until later in a didactic session and are testing them on residents.

The advent of ubiquitous mobile computing is transforming medical education to become more similar to education in fields such as law and business. In those fields, teaching is not just about imparting information; it is also about how to solve problems by learning information tools and using them to access data to solve problems.

Medical didactic sessions have the ability to go farther than those in law and business in ways that are truly exciting. The differential diagnosis after entering several findings of an educational case typically starts out with a disease or two missing and includes a disease or two that should not be there. Using the "Justify diagnosis" button (after enabling "Advanced mode"), one can explore why a disease is ranked as it is in the differential diagnosis. Typically, the misranked disease has one finding that is missing or is included inappropriately in the disease description, or the finding has its onset or offset misrecorded. As part of the didactic session, one can click the "Database" button and fix the relevant data point, and, immediately, the disease moves to a more appropriate place in the differential diagnosis. The corrected data point is sent automatically to be reviewed for inclusion in the next day's version of the database.

In the old days, a didactic session collected knowledge of a few people and the knowledge remained with them as long as they remembered it. Now, a didactic session can be part of an international network contributing to a database that learns from the wisdom of the community and leaves a lasting imprint in a decision support tool that everyone can use in real clinical cases.

The likely effect of ubiquitous computing on medical education is to put more emphasis on general skills, such as examination and history taking, that are learned through case-based education and put less emphasis on remembering details such as knowing each of the more than 1000 neurologic syndromes.

MEDICAL PUBLISHING: IMPLICATIONS FOR THE MEDICAL LITERATURE

In contrast to the deemphasis on detail in medical education, the effect on medical publishing is likely to be an increased emphasis on detail.

In child neurology, the age at onset and the age at disappearance of findings often are crucial to making diagnoses. However, in the medical literature, such age information is often missing from clinical reports, in part because it is difficult to obtain and in part because it makes for very dry reading and can be difficult for doctors to retain.

Despite the spottiness of the literature, at a very early stage in the diagnosis project, Isabelle Rapin made it abundantly clear to me that any diagnostic software that did not use onset information to its fullest would be ignoring the basics of child neurology and would not do a good job. Later, Marc Patterson made a similar point about the age at which some findings disappear in some diseases. It did not take long to conclude that each was right and add such capability to the software.

The ability to use such onset and offset information routinely in diagnostic software increases the importance of recording such information in medical publications, as well as recording quantitative information about the frequency of findings in diseases. Previously, such information would languish in articles and be forgotten by all except the few people who manage to retain such information. Now, such detail can be put to use for far more people, even if they have not read the papers yet, and can contribute toward making a diagnosis.

The advent of ubiquitous computing should be a reminder to clinical researchers of the importance of publishing the findings in a disease fully, including temporal information about the onset and offset of individual findings and quantitative information about the frequency of findings in diseases. Such information should be included in standard clinical papers and can also be submitted to databases such as that in *SimulConsult Neurological Syndromes* software, referencing publications in the medical literature if possible.

TECHNOLOGY FOR MOBILE MEDICAL COMPUTING

One hesitates to mention any specific details of computer hardware since the latest and greatest computer one day is often surpassed within months. Instead, I set forth the specifications I outlined beginning in November 2002, when Tablet PCs were first released.

Child neurologists define mobility for medical computing as meaning hardware able to fit into a white coat pocket. Full capability means the ability to run all standard computer software and access the Web using a regular Web browser. The biggest screen that can fit into a white coat pocket is best, optimally with at least 800 × 600 resolution. Thinner, lighter, cheaper, and faster hardware is better, as is a long-lasting power source. The ability to enter information without using a keyboard is a major plus, as is the ability to dock the computer and use a keyboard and large screen at a desk.

The first entrant that met these criteria was the Motion Computing (Austin, TX) LS800[6], which appeared in 2005. In 2006, Microsoft and Intel announced the Ultra-Mobile PC standard,[7] which meets all of these criteria except it allows a display as small as 800 × 480 resolution. Several manufacturers have announced Ultra-Mobile PC hardware.

As such devices improve in screen size, price, battery life, and wireless security, one would expect them to become more common in the medical setting.

PERSPECTIVES

Until recently, there was a split between computer hardware optimized for capability and computer hardware optimized for mobility. This split was due to technology too immature to deliver both capability and mobility in the same computer and the lack of software that demanded both capability and mobility. A new generation of white coat pocket–sized computers combining mobility and capability is ushering in an era in which mobile computing will be increasingly important for patient care. As a consequence, medical practice, education, and publishing will change in important ways.

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