Personal digital assistants in health care: experienced clinicians in the palm of your hand?

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Physicians and other health-care professionals are rapidly adopting personal digital assistants (PDA). Palm pilots and other hand-held computers are also increasingly popular among medical students. PDAs can be used for medical student education and physician training, daily clinical practice, and research. PDAs and their increasing integration with information technology in hospitals could change the way health care is delivered in the future. But despite the increasing use of PDAs, evidence from well-designed research studies is still needed to show how much these devices can improve the quality of care, save patients' lives, and ultimately reduce health-care expenses. In this Review of PDA use in health care, the operating systems, basic functionality, security and safety, limitations, and future implications of PDAs are examined. A personal perspective and an introduction to medical PDA applications, software, guidelines, and programmes for health-care professionals is also provided.

Health care in the developed world is characterised by a rapidly increasing use of information technology in patient care, increasing documentation, coding and billing requirements, the desire and need to access a wealth of clinical and basic science data on the internet, a fast growing number of electronic medical publications and online supplements to paper journals, instant communication needs of mobile medical professionals, application of multimedia technology in academic teaching, ad-hoc scientific data collection, and intelligent scheduling.

Traditionally, these needs were addressed independently with separate devices, reference systems, and networks. Personal digital assistants (PDAs) are capable of changing how health care is delivered in the future, since they aim to merge and integrate this functionality in one device that is versatile, customisable, and portable. According to polls, the worldwide PDA market had 10·5 million devices in 2003.

Clinicians are rapidly adopting PDAs into their daily practice.[1] In one study, more than half of all doctors younger than 35 years in developed countries used a PDA in 2003.[2] In a survey from the University of California (San Francisco, CA, USA) 40–50% of all US physicians and junior doctors (also referred to as residents in the USA) use or can use a PDA.[3] In 2005, the proportion of US doctors using PDAs is expected to be well above 50% and rising. This Review provides an overview of current PDA technologies, applications relevant to medical education and clinical practice, a guide to medical software, safety and security, a personal perspective, current limitations, and a future outlook.

Platforms and operating systems

In the past, hand-held computing was restricted to sophisticated programmable calculators with or without a data storage option. By comparison, most PDAs

Search strategy and selection criteria

I first searched in MEDLINE with the MeSH term "computers, handheld". The National Library of Medicine (NLM) summarises the following entry terms under this MeSH: "computer, handheld", "handheld computer", "handheld computers", "computers, palmtop", "computer, palmtop", "palmtop computer", "palmtop computers", "computers, palm-top", "computer, palm-top", "computers, palm top", "palm-top computer", "palm-top computers", "personal digital assistant", "digital assistant, personal", "PDA computer", "computer, PDA", "computers, PDA", "PDA computers", "palm pilot", "palm pilots", "pilot, palm", "pilots, palm", "pocket PC", "PC, pocket", "PCs, pocket", and "pocket PCs". For some subsearches, this MeSH term was combined with "evidence-based medicine" or "decision making, computer-assisted", covering the terms "decision making, computer assisted", "computer-assisted decision making", "computer assisted decision making", "medical decision making, computer-assisted", and "medical decision making, computer assisted". However, "computers, handheld" was only introduced in 2003 and now represents a subgroup of the microcomputer category (used to describe a broad spectrum of computers from 1992 to 2002). Therefore a second search was done of all non-indexed fields of MEDLINE for articles including the terms: "PDA", "personal digital assistant", "palm pilot", "palm top", "pocket computer", "pocket PC", "palm OS", "Windows mobile", "Windows CE", "handheld computer", "Smartphone", "evidence based medicine", "EBM", "decision tool", and "education". Google was used with similar search strategies as MEDLINE. Medical journals, hand-held computer magazines, online user forums, technical data sheets, software manuals, websites of device and software manufacturers, user groups, and medical libraries of leading medical institutions, and PDA devices were also reviewed. Since current research in MEDLINE on hand-held computers is mainly comprised of surveys, uncontrolled experiments, and individual reports, no formal evidence grade selection criteria to base a systematic review on could be developed and applied. However, priority was given to articles that at least attempted a controlled, masked, multicentric design, had meaningful sample sizes, included a statistical analysis or other objective outcome measures, and were published within the past 5 years.

currently run on the mobile operating systems of either Palm OS (PalmSource Inc, Sunnyvale, CA, USA) or Microsoft Windows (Microsoft Corp, Redmond, WA, USA) that, in addition to their intrinsic functionality, allow customisation by the installation of third-party software applications. Furthermore, some Palm OS or Windows mobile-based PDAs have a Java (Sun Microsystems, Santa Carla, CA, USA) runtime that allows the use of platform-independent, Java-based applications. Other platforms such as Newton (Apple Computer, Cupertino, CA, USA), Psion (Psion Teklogix, Mississauga, ON, Canada), BeOS (PalmSource Inc), Symbian OS (Symbian, London, UK), and Blackberry (Research in Motion, Waterloo, ON, Canada), currently have no major role in the health-care market.

In 1996, Palm Inc introduced the Pilot 1000 and Pilot 5000 products running the Palm OS operating system (PalmSource Inc) that led the resurgence of hand-held computing. In 1999, the company added advanced wireless communications capabilities to the Palm OS platform to address the demand for mobile information appliances. Their company policy to provide registered developers with access to the source code of the Palm operating system led to the development of more than 40 000 software applications, to run on more than 36 million Palm OS devices sold, unmatched by any other hand-held operating system so far.[4,5] Microsoft Windows mobile is Microsoft's most recent operating system for hand-held devices. Its source code is proprietary and only available to professional-device and software manufacturers.[6] Although Palm Inc still markets its own line of devices directly, both Palm OS and Windows mobile-based PDAs and smartphones (devices with a mobile phone and PDA combined) are also designed, manufactured, and distributed by several major computer manufacturers.

Basic functionality

PDAs are shirt-pocket-sized devices with a touch-sensitive screen, a dedicated input area or keyboard, customisable application buttons, and a multiway (button or mini joystick) navigator to browse information on the screen. Depending on the brand and model, some devices feature an expansion slot for memory cards or accessories, a built-in camera, headphone jacks, speaker, microphone, ports for infrared, Bluetooth, or Wi-Fi (Wireless Fidelity), and even built-in GPS (global positioning system) receivers.

PDAs are now generally equipped with a comprehensive suite of personal information management software or the option to integrate with common brands of such software, note-taking applications, and contact databases. PDAs can connect to desktop computers and wireless local area networks (W-LAN) using infrared, Bluetooth (first developed by Telefonaktiebolaget L M Ericsson, Stockholm, Sweden, now Bluetooth Special Interest Group [SIG], Delaware, DE, USA), or Wi-Fi communication technology. The desktop synchronisation software or additional add-on applications provide compatibility with popular office file formats. Most devices feature an e-mail application to integrate with current office suites, which allows users not only to carry critical files when travelling, but also to synchronise important files quickly and easily between desktop and hand-held devices.

Smartphones enhance the basic PDA functionality with wireless communication properties, including instant messaging, e-mail, web browsing, data synchronisation with remote servers and networks, and even video conferencing, if used in the coverage of commercial cellular telephone networks (figure 1).

Applications for health-care professionals

Physicians, nurses, dieticians, medical students and trainees, and other health-care professionals must review an ever-increasing amount of constantly changing information about their patients several times a day and correlate the data with the most recent diagnostic and therapeutic recommendations and management options to make sound decisions. Traditionally, health-care professionals consulted meticulously collected personal notebooks and article

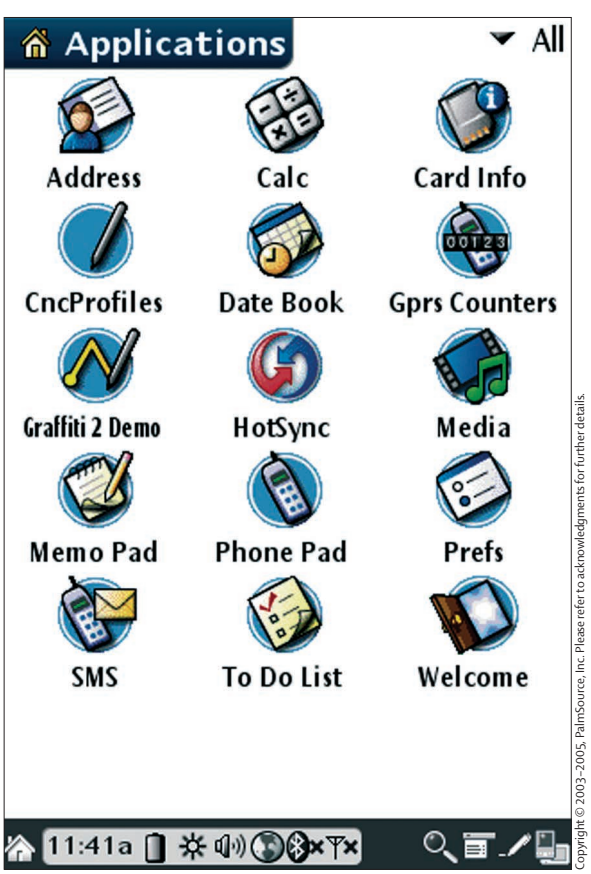

Figure 1: Basic PDA functionality of a sample main application screen on Palm OS 6.1

cut-outs, white-coat-pocket manuals, subscription journals, medical reference books, or electronic references on desktop computers.

The wealth of information and its constant changes due to the accelerated pace in translational research in biomedical science mean that these traditional resources are very difficult to keep up to date. Fast approval and propagation of newly discovered therapies by regulatory agencies such as the FDA (US Food and Drug Administration) or EMEA (European Medicines Agency) can also lead to more frequent recalls of drugs, medical products, and devices (as well as newly issued warnings); labelling changes; and novel interactions with existing compounds. Additionally, with the advent of overzealous documentation, coding, and billing requirements in managed care, constantly overworked health-care professionals cause an increasing number of treatment and management errors, because the time available to spend with patients is sadly diminishing. PDAs can help to overcome some of these problems.

PDA use in medical student education

The education of medical students now relies heavily on computer technology, beginning with the replacement of animal experiments by computer simulations in basic science laboratories, multimedia study programmes and exercises, and the abolition of paper-and-pencil board examinations for fully computerised systems in the USA and other countries. PDAs fit very well with these concepts, and the fact that medical students were among the earliest adopters of PDA use is unsurprising.[7]

Many medical schools require students to acquire basic clinical skills in clerkships. Faculty staff and students generally complete lengthy assessment forms at the end of the respective rotation, which do not always allow for a timely feedback and balanced learning experience. Electronic records of patient encounter and procedure logs maintained by the students on their PDAs, which are synchronised with either a central database or the mentor's desktop system, provide an interesting new approach. This concept has been assessed by several academic medical centres for rotations in internal medicine, family medicine, and emergency medicine in surveys. Medical students thought the logs were convenient to use. This system generally increased the number of patient encounters and recorded diagnoses, helped improve history-taking skills by alerting students to under-addressed issues such as women's health, improved overall computer literacy, allowed to immediately identify large gaps in basic clinical skills, and provided an easy mutual feedback with faculty staff during clinical clerkships.[8–14]

The early use of a clinical management approach to evidence-based medicine is a worthy goal in undergraduate medical education. Two studies were undertaken to investigate whether PDAs could assist this approach at the point of care. In both studies, medical students were given PDAs preloaded with either university-developed clinical-decision support software (CDSS) or a bundle of commercial-decision support applications commonly used by clinicians. Multivariable regression analysis showed that improved perceived usefulness of PDAs with CDSS was associated with supportive faculty attitudes, good knowledge of evidence-based medicine, enhanced computer literacy skills. Greater satisfaction with the CDSS than with commercial-decision support devices was associated with increased use in a clinical setting and improved success in search rates.[15] In the second study, pre-orientation and post-orientation questionnaires and a post-rotation assessment measured students' comfort levels, and the perceived usefulness of PDAs with CDSS and ratings of programmes on their PDAs were analysed. PDAs almost always enhanced the clerkship experience, although the outcome measures were not as clearly defined as those in the first study.[16]

The education effectiveness of evidence-based-medicine learning was investigated objectively in a randomised controlled trial, in which students' use of a PDA with CDSS was compared with the use of a pocket card containing guidelines and controls. Main outcome measures were factored and individual item scores from a validated questionnaire on personal, current, and future use of evidence-based medicine; use of evidence during and after the clerking of patients; frequency of discussions on the role of evidence during teaching rounds; and self-perceived confidence in clinical decision-making. The PDA showed significant improvements in all outcome scores, with the largest change in students' educational experience with evidence-based medicine. No substantial deterioration was seen in the improvements even after the withdrawal of PDAs during an 8-week washout period, which suggested at least short-term sustainability of PDA effects.[17]

PDAs can also assist in telementoring and multimedia learning. Two studies have shown the feasibility of live wireless transmissions of laparoscopic surgical procedures to PDAs. One of these studies also compared the recognition of anatomical landmarks on PDA screens with that of standard computer monitors during the procedure and showed significant improvements.[18,19] PDAs could also help enhance the classroom learning experience. In a pilot study, a histology class teacher polled the students about effectiveness, student interest, and comprehension with Bluetooth-equipped PDAs. End-of-class survey results indicated that students were enthusiastic about the polling device.[20]

Overall, current data lend support to the potential usefulness of PDAs in medical education. However, large randomised controlled trials with comparisons of PDA with non-PDA groups and with objective outcome measures, such as performance in in-house or board examinations, are needed to substantiate these early observations. Another important aspect of hand-held

computer-assisted learning is the integration of faculty staff, who are traditionally more reluctant to adopt new technology than students.[21]

PDA use in junior physician education

Several programmes for junior doctors at leading US academic institutions (such as Harvard Medical School, Boston, MA; Columbia College of Physicians and Surgeons, New York, NY; or Georgetown University Medical School, Washington, DC), have been early adopters of hand-held computers and provide their junior doctors with PDAs and software bundles.

Training programme accreditation authorities and medical specialty boards demand an ever-increasing documentation of patient exposure and procedural performance, to maintain and improve training standards. Apart from log cards, no simple and reliable mechanisms currently exist for directors of junior doctor programmes to assess how well their trainees are being exposed to teaching in their specialties and what curriculum weaknesses need to be addressed. Several studies in specialties such as anaesthesia, emergency medicine, family practice, general surgery, internal medicine, neurology, obstetrics and gynaecology, radiology, and urology, have demonstrated the usefulness of PDAs to simplify data collection and assess doctor and programme performance.[22–28]

A larger survey in junior doctors of six training programmes in family practice, internal medicine, neurology, paediatrics, radiology, and surgery concluded that, as advantages, many junior doctors readily adapted their personal organisers to help keep track of their clinical tasks and keep in touch with patients, and that commercial medical references were used most by the surveyed residents to answer immediate medical questions. The perceived drawbacks included: calculators and patients' trackers were not clearly able to be tailored to residents' needs (eg, to restrict and modify types of calculations to just those actually used), the physical size (both too small for display and too bulky overall), and several junior doctors mentioned a concern of becoming too dependent on one source of information, which was viewed as being too easy to lose or break. PDAs were widely used across the spectrum of specialties, irrespective of encouragement by the training programme.[29] PDAs can also assist in assessing the performance of clinical educators and students in objective structured clinical examinations (OSCE).[30,31]

The available data suggest the potential usefulness of PDAs in junior physician education. However, as concluded for medical student education, larger randomised controlled trials and surveys are needed to compare PDA-assisted training with traditional training in institutions and specialties by use of objective outcome measures, such as performance in in-house or board examinations, to define the role of PDAs in postgraduate medical education.

PDA use in daily clinical practice

PDAs are widely used among health-care professionals across all major specialties. A study of 2130 paediatricians selected randomly from the American Medical Associations' Physician Masterfile (American Medical Association, Chicago, IL, USA) aimed to calculate the percentage of paediatricians using PDAs, deduce the perceived strengths and weaknesses of PDAs, and explore characteristics associated with beliefs and use. The most commonly used applications were for drug reference (80%), followed by scheduling (67%), medical calculations (61%), prescription writing (8%), and billing (4%). PDA users were significantly more likely to be male, come from an urban community, have recently graduated from medical school, and work in non-private practice. Users were also more likely to believe that PDAs could reduce medical error, but often complained about memory capacity, although small screen size and system speed were not problems.[32] With 35–40% of respondents using a PDA, this study is a good example for mainstream hand-held computer use by physicians in many clinical specialties.

Drug reference and treatment safety

PDAs can replace bulky drug reference books and help with the selection and comparison of drugs, identification of dosing schedules, and dose adjustment when drug excretion is impaired. A major advantage of PDA use over paper-based drug references are drug interaction checks and—if updated (synchronised) with an institutional or commercial server regularly—the most up-to-date drug information and immediate access to alerts or recalls from regulatory or government agencies, such as the FDA or CDC (Centers for Disease Control, Atlanta, GA, USA). The usefulness of PDA-based drug references, including parenteral nutrition, blood products, and chemotherapy, and drug interaction checks has been established in several different studies.[33–39]

The effect of PDA use on medication safety can be even greater if use is extended to nursing staff and combined with patient identification systems. To improve patient safety in hospitals by reducing drug treatment and treatment errors, the FDA has published a final rule about bar code label requirements for human drugs and biological products, in February, 2004.[40] Bar codes are now required on most prescription drugs, blood, blood products, and specific over-the-counter drugs. This system begins when a patient is admitted to the hospital. The hospital gives the patient a bar-coded identification bracelet to link to his or her computerised medical record. As required by the FDA rule, most prescription drugs and specific over-the-counter drugs would have a bar code on their labels. The health-care team uses PDA-based bar-code scanners that are linked to the hospital's computer system of electronic medical records. Before a health-care worker gives a drug to the

patient, the health-care worker scans the patient's bar code, which allows the computer to access the patient's computerised medical record. The health-care worker then scans the drug that the hospital pharmacy has provided for treatment. This scan informs the computer which drug is being given. The computer then compares the patient's medical record with the drug being given to ensure that they match. Therefore some of the following problems (unfortunately not uncommon) could be easily avoided: wrong patient, wrong dose of drug, wrong drug, and wrong time to administer the drug. The technology is available and has already been implemented in some multisite facilities in the USA with some success.[41–46]

Patient scheduling, tracking, charting, and coding

Daily writing of progress notes with patients' data interpretation, management plans, and coding of medical treatments and procedures are crucial clinician responsibilities. However, the quality and legibility of notes are often inadequate. The following studies illustrate how the quality of medical records can be enhanced with PDA use. In a paediatric critical-care unit, researchers recorded documentation discrepancies in 60% of daily-progress notes. Therefore, they undertook a before-and-after trial to determine whether a point-of-care, PDA-based patient record and charting system could reduce discrepancies in progress note documentation by junior doctors in a neonatal intensive-care unit. They recorded significantly fewer documentation discrepancies.[47]

Another randomised study investigated whether hand-held computer-based documentation could improve both the quantitative and qualitative aspects of medical records in orthopaedic surgery. The electronic documentation consisted of a specially designed software package on a hand-held computer for bedside use with structured decision trees for examination, access to a history, and coding. In the control group, chart notes were compiled on standard paper forms and were subsequently entered into the hospital's information system. The number of documented ICD (International Classification of Diseases) diagnoses was the primary endpoint for sample size calculations. All patients' charts were reread by an expert panel, which assigned quality ratings to the different documentation systems by scrutinising the extent and accuracy of patients' histories and physical findings assessed by daily chart notes. Documentation with the hand-held computer significantly increased the median number of diagnoses per patients from four to nine, but it produced some over-coding for false or redundant items. Documentation quality ratings improved significantly with the introduction of the hand-held device with respect to the correct assessment of a patient's progress and translation into ICD diagnoses. Various learning curve effects were recorded with different operators.[48] These findings were confirmed by another orthopaedic surgery study in outpatients.[49]

A study among anaesthesiologists investigated their experience of using acute pain assessment software on a PDA for patient management. PDA assessments were more likely to contain documentation regarding pain and side-effects than paper assessments. The median time of the assessment period during the patient encounter was longer with the PDA than with paper; however, the median period for the total encounter time (chart review, assessment, documentation) was significantly shorter with the PDA than with paper.[50]

The battle between health insurers and physicians about claims is not over.[51] Claims are frequently denied or delayed on technicalities such as over-coding or under-coding, which PDA use could help in the future. Many clinicians have difficulty determining the appropriate code for current procedural terminology (CPT) or evaluation and management (E&M) to assign to the type and intensity of patient care they provide. Several surveys reported PDA-based charge capture and billing programmes were more accurate than paper. The reimbursement advantage was estimated to be 20%.[52–54]

PDA-based outcomes research to improve quality of care

Quality assessment and outcomes research in large medical associations require the acquisition, analysis of, and response to point-of-care data. Although most hospitals now process much of their clinical and administrative data electronically, data acquisition from the actual care providers and patients during encounters are still accomplished with an intermediate paper process. PDAs have the potential to simplify and accelerate this. Several studies, particularly in procedure-oriented specialties, have shown feasibility and measurable benefits of PDA-based data collection, because they allowed the quick modification of the study design, rapid data acquisition, and processing, to enable immediate effect of the results on clinical and administrative daily practice. This type of data collection increased performance almost instantly. Data were obtained with PDAs from either providers or patients to assess patient-perceived outcomes.[55–60]

PDA-based decision support, reference systems, and information retrieval

Quality of care can be improved with the implementation of CDSS (figure 2),[61] evidence-based medicine,[62] or other critically appraised publications and with alerting systems in hand-held computers. In a survey of 1538 health-sciences faculty staff and junior doctors, most responders indicated that they would like to learn more about clinical resources for PDAs.[63] Although many health-care professionals already rely on various sources of medical reference applications (figure 3),[64] their effect on the quality of care is currently under-explored. Pilot studies in which users either assessed an interface to

access institution-provided, critically appraised topics or headlines delivered to their PDAs alerting them to new books, National Guideline Clearinghouse guidelines, Cochrane reviews, and National Institute of Health (NIH) Clinical Alerts, as well as updated content in UpToDate (UptoDate, Waltham, MA, USA), Harrison's Online (McGraw Hill, Princeton, NJ, USA), Scientific American Medicine (now renamed ACP Medicine; American College of Physicians, Philadelphia, PA, USA), and Clinical Evidence. Participants could request additional information for any of the headlines, and the information that was delivered via e-mail during their next synchronisation was perceived as helpful.[65–68]

The Lister Hill National Center for Biomedical Communications (Bethesda, MD, USA), a research and development division of the National Library of Medicine (NLM) of the NIH, has undertaken a project to discover and implement design principles for point-of-care delivery of clinical support information. PubMed on Tap is an application for PDAs that retrieves MEDLINE citations directly from the PDA through a wireless connection to the internet. PubMed on Tap features include several PubMed search options, a history of previous queries, the ability to save citations to an electronic memo pad, two clustered results options, and links to journal websites.[69]

The National Cancer Institute (NCI; Bethesda, MD, USA), another NIH branch, has also recognised the need for new information delivery methods and is currently undertaking a research study that investigates how health-care professionals use cancer information on hand-held wireless devices. The AvantGo Enterprise 4.2 Solution (iAnywhere Solutions, Dublin, CA, USA) provided the platform to deliver the website content of NCI's cancer information service (CIS) onto hand-held devices. Several obstacles still need to be overcome before this service will be available to the general public.[70]

Other clinical settings where PDA-based decision support devices have been reported to be useful or advantageous include: emergency and mass casualty triage, data management of transplantation patients, management of patients with stroke, infection control, and enforcement of institution-specific, rational antibiotic use.[71–79] Although these concepts undoubtedly have potential, no study so far has compared this approach with existing methods of information delivery or performance of users in board examinations or re-certifications.

PDA use to educate and interact with patients

Most patients feel comfortable with their physicians using a PDA in daily clinical practice.[80] However, their use is not restricted to health-care providers. PDAs can serve as electronic patient diaries and prediction devices in diseases that are intermittently flaring, such as asthma or urticaria. The successful use of PDAs in diabetes care to improve glycaemia in patients with insulin pumps has been reported. PDAs can also help migraine patients to predict attacks.[81–88] The new use of PDAs in patients has also been recognised by government agencies such as the US Public Health Service (USPHS), which released an interactive programme for Palm PDAs to help patients quit smoking. The programme is distributed through the Agency for Healthcare Research and Quality (AHRQ) and is available on their website.[89] In addition to these professional applications, the internet is replete with software of the fitness, wellness, and personal health-care categories, such as menstrual calendars, diet, weight, calorie, and workout management applications, among others.

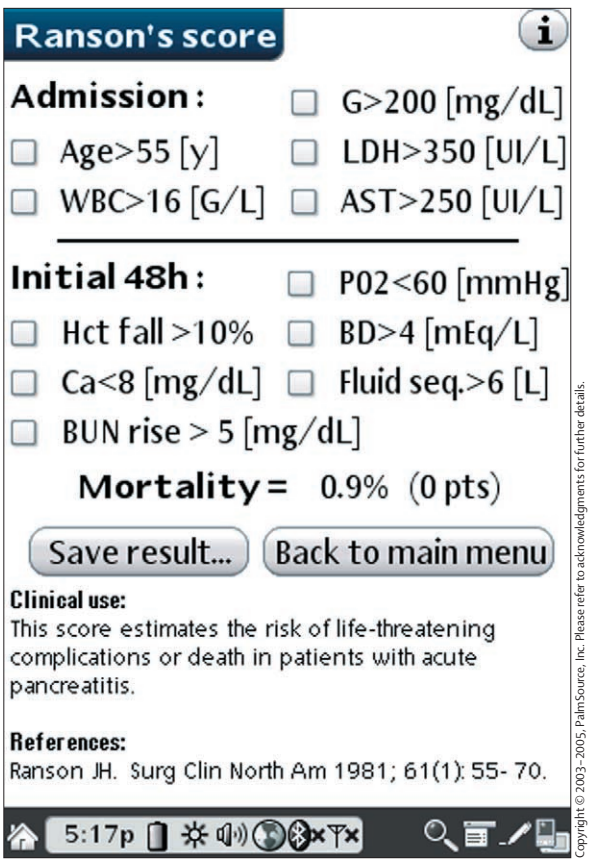

Figure 2: **Example of PDA-based software for clinical decision support**
MedCalc sample equation to calculate the Ranson's score to assist in the management of acute pancreatitis.[61] Reproduced with permission of Dr Mathias Tschopp, Geneva, Switzerland (developer of MedCalc).

Other evolving applications and uses in clinical practice

PDAs could help patients with brain dysfunction or injury as cognitive-behavioural orthoses.[90,91] A frequent outcome in these patients is memory impairment. One group of researchers designed and tested a mobile-distributed care system in a cognitive neurology day-care clinic of an academic medical centre.[92] A PDA-based speech synthesiser for speech-impaired patients has also been reported.[93] With an extended bandwidth of cellular

telephone networks (eg, universal mobile telecommunications system or UMTS) and high-speed institutional wireless networks, teleradiology on hand-held computers may become a reality. Pilot studies have shown promising data, such as CT scans that have been transmitted in the industry standard format of DICOM (digital image and communications in medicine) and that have been assessed remotely by radiologists. Echocardiograms have also been successfully read on PDAs.[94–96]

PDA use for data collection and processing in research

International, randomised, multicentre clinical trials usually need the collection, storage, and processing of large amounts of data. Data collection by investigators and study coordinators is traditionally done with specifically designed paper forms in clinical research files or complex telephone interview systems. Most trials also need the repeated completion of patient questionnaires to calculate standardised disease activity or quality-of-life scores. Unfortunately, paper-based, self-administered instruments remain inefficient for data collection because of missing information, respondent error, and slow data analysis due to processing delay from paper-to-computer file conversion. The advantages of PDAs to improve trial efficacy, quicken data analysis, and even improve patient safety due to earlier availability of results of interim analyses, among others, are obvious. Text and photo data capture, transmission feasibility, and visual analogue scales have been validated. [57,97–100]

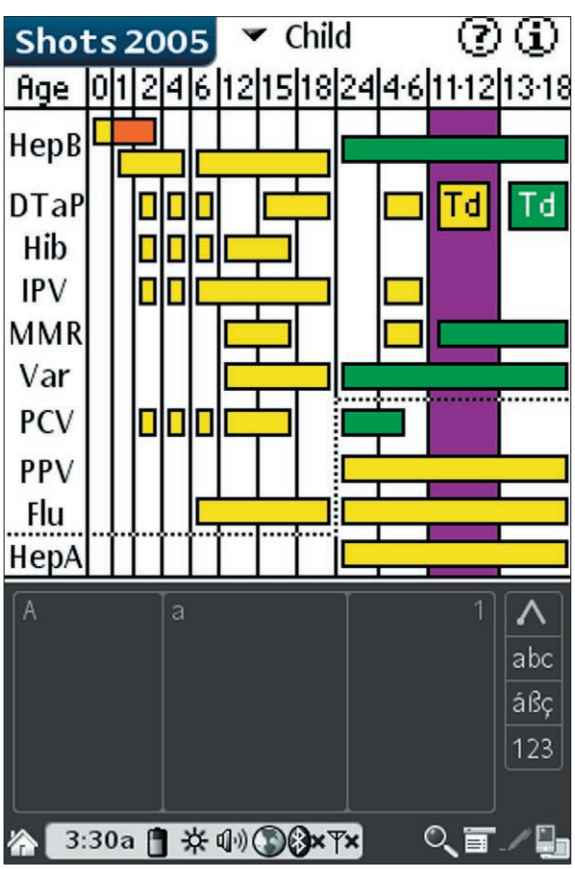

Figure 3: **Example of a guideline reference application**
Sample screen of the Shots 2005 application, developed by the Society of Teachers of Family Medicine and based on guidelines of the CDC National Immunization Program.[64] Reproduced with permission of Dr Richard K Zimmerman, University of Pittsburgh, PA, USA on behalf of the Group of Immunisation Education, Society of Teachers of Family Medicine.

PDA appliances can record, store, and transmit virtual electrocardiograms and electrochemical data.[101,102] There are comprehensive PDA-based data recorders that, in combination with a sensor vest, continuously encrypt and store patients' physiological data (ie, blood pressure, blood oxygen saturation, electroencephalograms, electro-oculograms, periodic leg movement, core body temperature, skin temperature, end tidal CO_2, and cough) on a memory card. Patients could also record time-stamped symptoms, moods, activities, and other endpoint-specific information in the recorder's digital diary. These features allow researchers to correlate multiple physiological indices that can be objectively measured with subjective input.[103]

Clinical research organisations have already discovered the advantages of PDA-based data collection in clinical trials. One such organisation and a major PDA manufacturer reported record sales of customised electronic diaries in 2004. This clinical research organisation has deployed 40 000 electronic diaries in 46 languages to 48 countries for use in clinical trials since 2000.[104]

How and where to find medical software for hand-held computers

Several thousands of medical software applications and documents are available for health-care professionals to use. Medical software can be grouped into major categories: standard medical textbooks and manuals adapted for PDAs, PDA-designed medical references, medical dictionaries, drug reference and interaction check programmes, medical calculators, medical prediction rule applets (a Java software component), document readers, medical image viewers, software for medical evidence retrieval, subscription platforms to electronic newsletters or journal digests, educational programmes for medical students, and medical alerting messaging; comprehensive medical enterprise solutions integrating with electronic medical records, patient management and scheduling systems, and electronic order, prescribing and pharmacy-dispensing systems, coding, billing and file-sharing. Software and content are available from commercial suppliers, shareware and freeware distributors, health-care organisations, and PDA enthusiasts.

The quality of medical software applications varies greatly and depends heavily on accessibility of the information. Initially, most suppliers offered static translations of traditional textbooks that were difficult to navigate. The market has now become more

	Website	Scope of products or services
American College of Physicians	http://www.acponline.org/pda	Offers a portable decision support programme, Palm documents with up-to-date information on bioterrorism threats and substance, uniform requirements for manuscripts from the International Committee of Medical Journal Editors, helpful tables for physicians instructing medical students and residents, an ethics manual, and many other helpful medical documents. Access is free.
British Medical Journal (*BMJ*) PDA webpages	http://bmj.bmjjournals.com/cgi/content/full/324/7334/DC2	List of medical resources available for hand-held devices that can be accessed freely. The list contains short descriptions of the respective applications, comments from developers and users, and documents and links to distributors.
Ectopic Brain	http://pbrain.hypermart.net/medapps.html	Designed to serve as a starting point for physicians interested in exploring the potential of Palm OS hand-held computers in clinical practice. Includes a good introduction to hand-held computing, and a constantly updated archive of medical documents and software applications for Palm PDAs.
Medical Piloteer Webring	http://w.webring.com/hub?ring=medpilot	Dedicated to linking sites that provide medical or health-care resources for hand-held devices.
Mobile Medica	http://www.apprisor.com	Publishes practice guidelines and meeting abstracts of several medical societies.
Pediatrics on Hand	http://www.pediatricsonhand.com	Outstanding resource on paediatric PDA applications for health-care professionals and parents to use.
Journal of Mobile Informatics	http://www.pdacortex.com	Online journal offering medical PDA product reviews, discussion forums, documents, and software.
Uniformed Services Academy of Family Physicians	http://www.usafp.org	Offers free medical software applications and documents. Focuses on primary care, and emergency and military medicine, with a good introduction to palm computing in general.
University of Connecticut	http://library.uchc.edu/pda/	One of the most comprehensive websites of medical hand-held computing with a superb link list.
Vertical PDA Network	http://www.pdamd.com	Maintains resources dedicated to the promotion and education of health-care professionals on the use of mobile and wireless technology. Offers news articles, product reviews, and software and hardware sales.

Table 1: **Websites (and their providers) dedicated to hand-held computing for medical professionals**

sophisticated, demanding more dynamic content with frequent updates taking advantage of the implementation of wireless networking protocols in PDAs. Internet websites are available to link users to sites dedicated to medical PDA use (table 1), major medical software suppliers (webtable 1), guidelines from professional societies or health-care agencies (table 2), and helpful programmes for general PDA use (webtable 2). Additionally, some medical journals such as the *Journal of the American Medical Association* (*JAMA*) regularly announce and discuss novel hand-held computer software titles (figure 4).

A personal perspective

As an internist and gastroenterologist, I face the same challenges that all academic physicians do: attending on the wards, clinics, critical care units, and emergency rooms; doing consultations for other specialties; dealing with numerous conferences, administrative work, lecturing, and bedside teaching; being an investigator in clinical trials; mentoring doctoral students; and running a basic science research laboratory, which often hardly fit into those 24 hours, unless one is very organised. I perceived the arrival of the Palm Pilot (Palm Inc, Sunnyvale, CA, USA) in 1996 as a blessing; it quickly changed how I organised my day, kept abreast of the ever-changing specialties of medicine and biomedical science, obtained and accessed medical information, and taught students. My old spiral notebook is retired now.

On a typical day, my PDA wakes up 30 minutes before I do, logs on to my notebook as well as the internet, and synchronises and updates all PDA applications. Not only are contacts, appointments, and medical references kept up to date in this way, but my PDA e-mail application is also programmed to retrieve exclusive e-mails such as electronic tables of contents from medical journals, alerts from the FDA Medwatch system, and other resources in my e-mail inbox. On the way to work I can review, mark, and erase these e-mails. Once at the hospital, my PDA reminds me of conferences, meetings, and displays a to-do list for the day. When I see patients, I rely on drug reference and interaction applications, institutional microbial spectra databases, medical calculators, prediction rules, and specific topics in PDA editions of popular medical reference manuals. Additionally, I have many guidelines from our institution, professional organisations, and agencies, as well as pdf excerpts from journal articles stored in my memory card. I do not believe PDA versions of large medical textbooks are helpful, because they are often difficult to navigate. I am currently investigating the usefulness of the new PubMed on Tap programme, whenever I have access to the institutional W-LAN.

See Lancet Online for webtables 1 and 2

Our department receives a fair amount of patients with gastrointestinal cancers. Staging of uncommon cancers is easy with a TNM (tumour, node, metastasis) staging programme. I can customise and print actual chemotherapy protocols with a shareware application. An add-on to this shareware application allows me to programme and print protocols for rare cancers. At ward rounds with students, I take full advantage of the multimedia capabilities of my PDA: I can display images from my personal medical image library or other PDA reference materials, play heart murmur or lung sound recordings, and use the screen to quickly sketch something to make a teaching point. I can carry and share with students (via infrared) a self-created collection of text notes, customised to the patients we see together.

In clinics where I see many patients enrolled in clinical trials, I quickly enter, access, and sort essential data on spreadsheets. The spreadsheets were created with my notebook spreadsheet application, transferred to and updated on my PDA with a commercial programme.

This software also helps me to review and store my presentations for lectures and talks. New versions of PDAs can also act as USB memory sticks. At the end of the day, my PDA synchronises and backs up the day's data with my notebook before it charges for the night (webtable 1).

PDA safety and security

Information recording and interchange always raise the question of security and privacy. Overall, PDA security hazards are probably similar to other computers used in hospitals and elsewhere. Catastrophic data loss can only be prevented with regular backups. PDA viruses have been reported for the mobile operating system from Microsoft Windows and also, to a lesser degree, for the Palm operating system. Major security firms are addressing this problem with the development of commercial antivirus products for hand-held devices.

In the USA, PDA-based patient data processing and storage must comply with the Health Information Portability and Accountability Act (HIPAA) of 1996. The Centers of Medicare and Medicaid Services (CMS) of the

	Website	Scope
American Academy of Family Physicians (AAFP)	http://www.apprisor.com	Offers a downloadable summary of policy recommendations for periodic health examinations.
American College of Cardiology (ACC)	http://www.acc.org/clinical/palm_download.htm	The ACC has contracted Skyscape to convert its guidelines into a PDA accessible format. The application can be downloaded for free from the ACC website.
American College of Chest Physicians	http://www.chestnet.org/education/guidelines/currentGuidelines.php	The seventh ACCP conference on antithrombotic and thrombolytic therapy, ACP/ACCP management of acute exacerbations of COPD algorithm, guidelines for diagnosis and management of lung cancer, assessment of diagnostic tests for ventilator-associated pneumonia, guidelines for weaning and discontinuing ventilatory support, and a guideline on cough management as a defence mechanism and as a symptom, as well as pulmonary rehabilitation are available for download.
American College of Physicians (ACP)	http://www.acponline.org/annalspdaservices/collections/index.html	The ACP offers updates for subspecialties, ACP multiple small feedings of the mind, common ICD-9 codes, guide to bioterrorism identification, and guides to chemical terrorism identification through Apprisor for PDA download. On its own website, the ACP provides several documents and guides for evidence based medicine approach to common medical problems.
American Heart Association (AHA)	http://www.apprisor.com	The AHA distributes its guidelines through Apprisor.
DHHS HIV and AIDS medical practice guidelines	http://www.aidsinfo.nih.gov/guidelines/	The US Department of Health and Human Services offers guidelines for the use of antiretroviral drugs in HIV-infected children, adolescents, pregnant women, and adults, and the prevention of opportunistic infections in patients with HIV.
DHSS AIDS Info drug database and HIV/AIDS glossary	http://aidsinfo.nih.gov/mobile/	The US Department of Health and Humand Services offers a programme for possible sexual, injecting-drug-use, or other non-occupational exposure to HIV, including considerations related to antiretroviral therapy.
National Asthma Education Prevention Expert Panel (NAEPP)	http://hin.nhlbi.nih.gov/as_palm.htm	The National Heart, Lung, and Blood Institute (NHLBI) offers evidence-based applications for asthma treatment its own website.
National Cancer Institute (NCI) Cancer Staging and Treatment	http://www.palmgear.com/index.cfm?fuseaction=software.showsoftware&PartnerREF=&siteid=1&prodID=7862	The NCI Cancer Information Service offers one of the most comprehensive cancer databases. It contains peer-reviewed summaries on cancer treatment, screening, prevention, genetics, and supportive care, and complementary and alternative medicine; a registry of about 2000 open and 13 000 closed cancer clinical trials worldwide; and directories of physicians, professionals who provide genetics services, and organisations that provide cancer care.
National Cholesterol Education Program (NCEP)	http://hin.nhlbi.nih.gov/atpiii/atp3palm.htm	Through Apprisor the NHLBI distributes the NCEP ATP III quick reference.
National Guideline Clearinghouse (NGC) PDA documents	http://www.guideline.gov	Public resource for evidence-based clinical practice guidelines. NGC is a collaborative initiative of the US Agency for Healthcare Research and Quality (AHRQ) and US Department of Health and Human Services. NGC was originally created by AHRQ in partnership with the American Medical Association and the American Association of Health Plans. All NGC summaries are available in a text format and downloadable to PDAs.
Obesity Education Initiative (OEI) Guidelines on Overweight and Obesity in Adults	http://hin.nhlbi.nih.gov/obgdpalm.htm	The NHLBI offers evidence-based medicine applications for asthma treatment, cholesterol management, and obesity education in its own website. Through Apprisor the NHLBI distributes the joint national committee on management of hypertension (JNC 7) report reference card and the NCEP ATP III quick reference.
The National Quality Measures Clearinghouse	http://www.qualitymeasures.ahrq.gov/about/pdadownload.aspx	The National Quality Measures Clearinghouse (NQMC), sponsored by the AHRQ, US Department of Health and Human Services, is a database and website for information on specific evidence-based health care quality measures. NQMC is sponsored by AHRQ to promote widespread access to quality measures by the health-care community and other interested individuals. Brief summaries of all measures can be viewed and downloaded in various formats, including PDA-compatible formats.
Tuberculosis Treatment and Sexually Transmitted Diseases Guidlines of the Centers for Disease Control and Prevention (CDC)	http://www.cdc.gov/nchstp/tb/pubs/PDA_TBGuidelines/PDA_treatment_guidelines.htm	The CDC publishes a PDA guide on the management of tuberculosis and yearly updated guide on the management of sexually transmitted disease. All resourced can be downloaded free of charge.
US Agency for Healthcare Research and Quality (AHRQ) Pneumonia tool	http://pda.ahrq.gov/clinic/psi/psi.htm	Useful interactive application to assist clinicians in determining the most appropriate care for newly diagnosed cases of community-acquired pneumonia at the point of care. It will help calculate the severity index of a pneumonia patient. The output includes mortality rates and pneumonia class types.
US Preventive Services Task Force (USPSTF) Guidelines	http://www.acponline.org/annalspdaservices/collections/index.html	The USPSTF guidelines were published in the Annals of Internal Medicine and can be downloaded from the ACP website .
USPSTF clinical preventive services PDA programme	http://198.76.191.14/ipss/ipss.htm	The USPSTF also offers an interactive PDA application that identifies clinical preventive services for screening, counselling, and preventive medication based on the patient's age, sex, and pregnancy status. The application is slow and consumes a lot of memory. An alternative programme named "Recs" was developed by Dr Jeff Weinfeld at Georgetown University, Washington, DC, USA. It is easy to install and navigate and covers the same content. This programme can be downloaded at http://gumc.georgetown.edu/departments/familymed/drweinfeld.html.

Table 2: **Professional society and health-care agency guidelines**

US Department of Health and Human Services provide information technology professionals and the general public with extensive resources to address the issues on their information security programme website.[105] In addition to a general policy manual, the CMS has outlined fundamental regulations as well as system architecture and security requirements for the acquisition, storage, management, and transmission of patient data. As a general rule, these policies are developed to provide a defence-in-depth security structure, along with a least-privilege approach and a need-to-know basis for all information access. Developers can download security threat identification resources based on their occurrence and importance in the current CMS environment. Before approval, applications have to pass the contractor assessment security tool (CAST) test to record their compliance with the CMS.

Several specific new risks and vulnerabilities arise with wireless networks. Bluejacking (ie, unauthorised accessing of Bluetooth-enabled devices) in airports and other public places is advancing to a new hacker sport. These problems need to be addressed by hardware and software makers with improved encryption and authentication technology. Currently, no evidence shows that wireless-enabled PDAs interfere with the functioning of implanted cardiac pacemakers or defibrillators.[29,106–108]

Challenges of current PDA technology and future outlook

Evidence of PDA use and dominance in medical education, clinical practice, and research is still evolving. Most studies available so far have not been randomised, controlled, or are multicentric in design. The fact that physicians can carry an entire shelf of medical reference textbooks on a hand-held computer's memory card does not automatically mean that physicians know their contents or can apply their knowledge appropriately in clinical practice. The increasing incidence of the so-called palmomental reflex by residents and medical students should remind clinical educators that PDAs are not peripheral brains and are a poor substitute for ad-hoc clinical knowledge.[109]

At a time when governments, health-care organisations, and insurers worldwide cannot stop entertaining the themes of necessity assessment, cost saving, and down-sizing, we need convincing arguments that the extra expenses of investment into PDA technology can actually improve quality of care, save lives, and ultimately save health-care costs.[110] The IT industry has recognised health care as the next big market.[111,112] It will be up to health-care professionals who depend on PDAs to inform PDA manufacturers of users' true needs, do the necessary research, and actively direct the development of new hardware and software.

The future of information exchange in medicine is digital and wireless.[113] What will a medical PDA look like

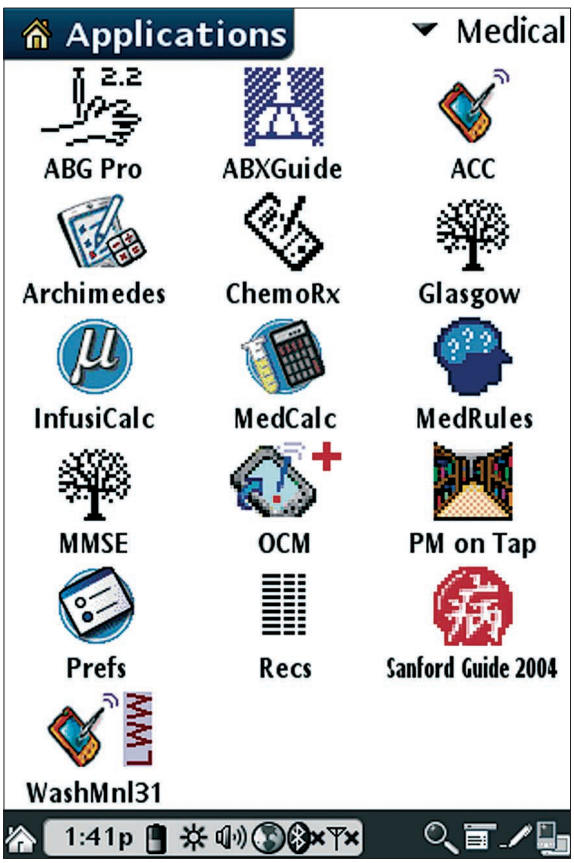

Figure 4: Examples of common medical software

in 2015? It will probably be housed in a ceramic or lightweight alloy case, and hopefully be no larger but substantially lighter than current shirt-pocket-sized devices. New semiconductor technology will allow hand-held computers to be equipped with processors that can handle much more work than the best desktop systems that are currently available, while consuming less power to extend battery life. Memory will no longer be an issue, because data will be mainly kept in network storage systems. Manual data entry is still a problem in current versions of PDAs. In the future, authorised, secure logons to the PDA and data entry will be done with combined speech and fingerprint recognition by sophisticated audio hardware and a new high-resolution generation of touch-sensitive screens. Graffiti 2 (PalmSource Inc) characters will be further developed into true handwriting recognition. Speech processing will also be a reality, replacing many dictation methods currently used.

Very high network speeds will provide immediate access to clinical and administrative data, including imaging information such as procedural movies; three-dimensional ultrasonography; CT, MRI, or PET scans; histological slides; microbial cultures; and institutional and remote reference systems at any place and time. Medical applications will go beyond organisation and

storage of information. PDAs could evolve into expert systems that access information from many sources (ie, classic textbook style references, data from basic and clinical research and genome scans, environmental and public-health information, and results from ongoing clinical trials, match the information with the patient's medical records from current or past admissions or visits, apply prediction rules, calculate clinical equations, and integrate all the data into an overall information package for clinicians. Users will be able to obtain and share opinions on patients with colleagues and international experts with ad-hoc medical multimedia conferencing.

PDA-based medical information management could even have an environmental effect that goes beyond paper-saving. The environmental effects of two applications of wireless technologies were compared with those of conventional technologies.[114] Compared with the use of a newspaper, users receiving the news on a PDA resulted in the release of 32–140 times less CO_2, several orders of magnitude less NO_x and SO_x, and the use of 26–67 times less water than the use of newspapers. Wireless teleconferencing resulted in one to three orders of magnitude less CO_2, NO_x, and SO_2 emissions than those from business travel.

Is this future scenario widely off the mark? Perhaps so, but critics should remember that many theoretical predictions of the future have inspired the design of devices used today. However, it is still certain that no computer system can ever replace dedicated, experienced clinicians and their empathic interaction with patients and families.

Conflict of interest statement

I declare that I have no conflict of interest.

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References

1 Medicine on the move. PDAs and tablet PCs make the rounds with doctors and nurses. *Postgrad Med* 2004; **115** (suppl): i–vi.
2 Martin S. More than half of MDs under age 35 now using PDAs. *CMAJ* 2003; **169**: 952.
3 Miller RH, Hillman JM, Given RS. Physician use of IT: results from the Deloitte Research Survey. *J Healthc Inf Manag* 2004; **18**: 72–80.
4 PalmSource. PalmSource website. http://www.palmsource.com (accessed July 1, 2005).
5 palmOne. palmOne website. http://www.palmone.com (accessed July 1, 2005).
6 Microsoft. Windows mobile-based pocket PCs. http://www.microsoft.com/windowsmobile/pocketpc/ppc/default.mspx (accessed July 1, 2005).
7 Topps D, Thomas R, Crutcher R. Introducing personal digital assistants to family physician teachers. *Fam Med* 2003; **35:** 55–59.
8 Engum SA. Do you know your students' basic clinical skills exposure? *Am J Surg* 2003; **186:** 175–81.
9 Autry AM, Simpson DE, Bragg DS, et al. Personal digital assistant for "real time" assessment of women's health in the clinical years. *Am J Obstet Gynecol* 2002; **187:** S19–S21.
10 Kurth RJ, Silenzio V, Irigoyen MM. Use of personal digital assistants to enhance educational evaluation in a primary care clerkship. *Med Teach* 2002; **24:** 488–90.
11 Lee JS, Sineff SS, Sumner W. Validation of electronic student encounter logs in an emergency medicine clerkship. *Proc AMIA Symp* 2002; 425–29.
12 Seago BL, Schlesinger JB, Hampton CL. Using a decade of data on medical student computer literacy for strategic planning. *J Med Libr Assoc* 2002; **90:** 202–09.
13 Denton GD, Williams RW, Pangaro L. Core problems reported by students in a palm OS and Internet-based problem entry system predicts performance on the third-year internal medicine clerkship. *AMIA Annu Symp Proc* 2003; 827.
14 Bakken S, Sheets CS, Curtis L, Soupios M, Curran C. Informatics competencies pre-and post-implementation of a Palm-based student clinical log and informatics for evidence-based practice curriculum. *AMIA Annu Symp Proc* 2003; 41–45.
15 Johnston JM, Leung GM, Tin KY, Ho LM, Lam W, Fielding R. Evaluation of a handheld clinical decision support tool for evidence-based learning and practice in medical undergraduates. *Med Educ* 2004; **38:** 628–37.
16 Sutton J, Stockton L, McCord G, Gilchrist VJ, Fedyna D. Handheld computer use in a family medicine clerkship. *Acad Med* 2004; **79:** 1114–19.
17 Leung GM, Johnston JM, Tin KY, et al. Randomised controlled trial of clinical decision support tools to improve learning of evidence based medicine in medical students. *BMJ* 2003; **327:** 1090.
18 Gandsas A, McIntire K, Park A. Live broadcast of laparoscopic surgery to handheld computers. *Surg Endosc* 2004; **18:** 997–1000.
19 Gandsas A, McIntire K, Montgomery K, Bumgardner C, Rice L. The personal digital assistant (PDA) as a tool for telementoring endoscopic procedures. *Stud Health Technol Inform* 2004; **98:** 99–103.
20 Menon AS, Moffett S, Enriquez M, Martinez MM, Dev P, Grappone T. Audience response made easy: using personal digital assistants as a classroom polling tool. *J Am Med Inform Assoc* 2004; **11:** 217–20.
21 McLeod TG, Ebbert JO, Lymp JF. Survey assessment of personal digital assistant use among trainees and attending physicians. *J Am Med Inform Assoc* 2003; **10:** 605–07.
22 Bird SB, Zarum RS, Renzi FP. Emergency medicine resident patient care documentation using a hand-held computerized device. *Acad Emerg Med* 2001; **8:** 1200–03.
23 Fischer S, Lapinsky SE, Weshler J, et al. Surgical procedure logging with use of a hand-held computer. *Can J Surg* 2002; **45:** 345–50.
24 Joy S, Benrubi G. Personal digital assistant use in Florida obstetrics and gynecology residency programs. *South Med J* 2004; **97:** 430–33.
25 MacNeily AE, Nguan C, Haden K, Goldenberg SL. Implementation of a PDA based program to quantify urology resident in-training experience. *Can J Urol* 2003; **10:** 1885–90.
26 Vincent C, Kim S, Schneeweiss R, Stevens N. Documenting procedures and deliveries during family practice residency: a survey of graduates' experiences, preferences, and recommendations. *Fam Med* 2003; **35:** 264–68.
27 Brilla R, Wartenberg KE. Introducing new technology: handheld computers and drug databases. A comparison between two residency programs. *J Med Syst* 2004; **28:** 57–61.
28 Sequist TD, Singh S, Pereira A, Pearson SD. On Track: a database for evaluating the outpatient clinical experience of internal medicine residency training. *AMIA Annu Symp Proc* 2003; 1002.
29 Barrett JR, Strayer SM, Schubart JR. Assessing medical residents' usage and perceived needs for personal digital assistants. *Int J Med Inform* 2004; **73:** 25–34.

30 McGowan JJ, Bangert M, Ballinger SH, Highbaugh S. Implementing wireless evaluation in a hospital-based OSCE center. *AMIA Annu Symp Proc* 2003; 930.

31 Lye P, Heidenreich C, Wang-Cheng R, Bragg D, Simpson D, Ta TA. Experienced clinical educators improve their clinical teaching effectiveness. *Ambul Pediatr* 2003; **3:** 93–97.

32 Carroll AE, Christakis DA. Pediatricians' use of and attitudes about personal digital assistants. *Pediatrics* 2004; **113:** 238–42.

33 Enders SJ, Enders JM, Holstad SG. Drug-information software for Palm operating system personal digital assistants: breadth, clinical dependability, and ease of use. *Pharmacotherapy* 2002; **22:** 1036–40.

34 Clauson KA, Seamon MJ, Clauson AS, Van TB. Evaluation of drug information databases for personal digital assistants. *Am J Health Syst Pharm* 2004; **61:** 1015–24.

35 Grasso BC, Genest R, Yung K, Arnold C. Reducing errors in discharge medication lists by using personal digital assistants. *Psychiatr Serv* 2002; **53:** 1325–26.

36 Barrons R. Evaluation of personal digital assistant software for drug interactions. *Am J Health Syst Pharm* 2004; **61:** 380–85.

37 Robinson RL, Burk MS. Identification of drug-drug interactions with personal digital assistant-based software. *Am J Med* 2004; **116:** 357–58.

38 Miller SM, Beattie MM, Butt AA. Personal digital assistant infectious diseases applications for health care professionals. *Clin Infect Dis* 2003; **36:** 1018–29.

39 France DJ, Miles P, Cartwright J, et al. A chemotherapy incident reporting and improvement system. *Jt Comm J Qual Saf* 2003; **29:** 171–80.

40 US Food and Drug Administration (FDA). Bar code label requirements for human drug products and biological products. http://www.fda.gov/oc/initiatives/barcode-sadr/fs-barcode.html (accessed July 1, 2005).

41 BD Biosciences. BD.id patient identification system. http://www.bd.com/bdid/ (accessed July 1, 2005).

42 McKesson. Horizon Admin-Rx and Robot-Rx. http://www.mckessonautomation.com/wt/auto/tech_fornursing_admin (accessed July 1, 2005).

43 Chan JC, Chu RW, Young BW, et al. Use of an electronic barcode system for patient identification during blood transfusion: 3-year experience in a regional hospital. *Hong Kong Med J* 2004; **10:** 166–71.

44 Kester M. Bar coding at the bedside. New England hospital implements an automated point-of-care medication administration system to reduce medication errors and their associated complications. *Health Manag Technol* 2004; **25:** 42–44.

45 Turner CL, Casbard AC, Murphy MF. Barcode technology: its role in increasing the safety of blood transfusion. *Transfusion* 2003; **43:** 1200–09.

46 Kaushal R, Bates DW. Information technology and medication safety: what is the benefit? *Qual Saf Health Care* 2002; **11:** 261–65.

47 Carroll AE, Tarczy-Hornoch P, O'Reilly E, Christakis DA. The effect of point-of-care personal digital assistant use on resident documentation discrepancies. *Pediatrics* 2004; **113:** 450–54.

48 Stengel D, Bauwens K, Walter M, Kopfer T, Ekkernkamp A. Comparison of handheld computer-assisted and conventional paper chart documentation of medical records. A randomized, controlled trial. *J Bone Joint Surg Am* 2004; **86-A:** 553–60.

49 Lou E, Fedorak MV, Hill DL, Raso JV, Moreau MJ, Mahood JK. Bluetooth wireless database for scoliosis clinics. *Med Biol Eng Comput* 2003; **41:** 346–49.

50 VanDenKerkhof EG, Goldstein DH, Lane J, Rimmer MJ, Van Dijk JP. Using a personal digital assistant enhances gathering of patient data on an acute pain management service: a pilot study. *Can J Anaesth* 2003; **50:** 368–75.

51 Kesselheim AS, Brennan TA. Overbilling *vs* downcoding—the battle between physicians and insurers. *N Engl J Med* 2005; **352:** 855–57.

52 Handler SM, Hsieh VC, Nace DA, Sciulli L, Fridsma DB, Studenski SA. Development and evaluation of a charge capture program for long-term care providers. *J Am Med Dir Assoc* 2004; **5:** 337–41.

53 Silva MA, Tataronis GR, Maas B. Using personal digital assistants to document pharmacist cognitive services and estimate potential reimbursement. *Am J Health Syst Pharm* 2003; **60:** 911–15.

54 Howard WR. Respiratory care billing using a personal digital assistant. *Respir Care* 2004; **49:** 1339–48.

55 Robertson J. Cardiovascular point of care initiative: enhancements in clinical data management. *Qual Manag Health Care* 2003; **12:** 115–21.

56 Hughes RA, Sinha A, Aspinal F, Dunckley M, Addington-Hall J, Higginson IJ. What is the potential for the use of clinical outcome measures to be computerised? Findings from a qualitative research study. *Int J Health Care Qual Assur Inc Leadersh Health Serv* 2004; **17:** 47–52.

57 Saleh KJ, Radosevich DM, Kassim RA, et al. Comparison of commonly used orthopaedic outcome measures using palm-top computers and paper surveys. *J Orthop Res* 2002; **20:** 1146–51.

58 Bonsanto MM, Hamer J, Tronnier V, Kunze S. A complication conference for internal quality control at the neurosurgical department of the University of Heidelberg. *Acta Neurochir Suppl* 2001; **78:** 139–45.

59 Fu Q, Xue Z, Klein G. Using mobile information technology to build a database for anesthesia quality control and to provide clinical guidelines. *Stud Health Technol Inform* 2003; **95:** 629–34.

60 Astrahan MA. HDR quality assurance methods for personal digital assistants. *Med Dosim* 2004; **29:** 166–72.

61 MedCalc. MedCalc Palm OS. http://www.med-ia.ch/medcalc/ (accessed July 1, 2005).

62 Weinfeld J. Rx for Prevention (Recs) 1.0. http://gumc.georgetown.edu/departments/familymed/drweinfeld.html (accessed July 1, 2005).

63 De Groote SL, Doranski M. The use of personal digital assistants in the health sciences: results of a survey. *J Med Libr Assoc* 2004; **92:** 341–48.

64 Society of Teachers of Family Medicine. Shots 2005. http://www.immunizationed.org/anypage.aspx?pagename=shotspalm (accessed July 1, 2005).

65 Dong P, Mondry A. Enhanced quality and quantity of retrieval of critically appraised topics using the CAT crawler. *Med Inform Internet Med* 2004; **29:** 43–55.

66 Johnson ED, Pancoast PE, Mitchell JA, Shyu CR. Design and evaluation of a personal digital assistant- based alerting service for clinicians. *J Med Libr Assoc* 2004; **92:** 438–44.

67 Barber N. Designing information technology to support prescribing decision making. *Qual Saf Health Care* 2004; **13:** 450–54.

68 Chen ES, Mendonca EA, McKnight LK, Stetson PD, Lei J, Cimino JJ. PalmCIS: a wireless handheld application for satisfying clinician information needs. *J Am Med Inform Assoc* 2004; **11:** 19–28.

69 Lister Hill National Center for Biomedical Communications of the National Library of Medicine (NLM). PubMed on tap. http://archive.nlm.nih.gov/proj/pmot/downloadPalm.php (accessed July 1, 2005).

70 US Department of Health and Human Services (DHHS). PDA usability study. http://usability.gov/lessons/handhelds.html (accessed July 1, 2005).

71 Kawamoto K, Drew R, Huang M, Coleman A, Brown T, Adams M. CustomID: A highly customizable infectious diseases management tool for providing institution-specific decision support on the web and PDA. *Medinfo* 2004; **2004:** 1677.

72 Goss L, Carrico R. Get a grip on patient safety: outcomes in the palm of your hand. *J Infus Nurs* 2002; **25:** 274–79.

73 Krause A, Hartl D, Theis F, Stangl M, Gerauer KE, Mehlhorn AT. Mobile decision support for transplantation patient data. *Int J Med Inform* 2004; **73:** 461–64.

74 Barshick B. How PDAs can speed up the organ transplant process. *Nursing* 2004; **34:** 68.

75 Ray HN, Boxwala AA, Anantraman V, Ohno-Machado L. Providing context-sensitive decision-support based on WHO guidelines. *Proc AMIA Symp* 2002; 637–41.

76 Quaglini S, Caffi E, Boiocchi L, Panzarasa S, Cavallini A, Micieli G. Web-based data and knowledge sharing between stroke units and general practitioners. *AMIA Annu Symp Proc* 2003; 534–38.

77 Chang P, Hsu Y, Tzeng Y, Hou IC, Sang YY. Development and pilot evaluation of user acceptance of advanced mass-gathering emergency medical services PDA support systems. *Medinfo* 2004; 1421–25.

78 Cady G. 200 city survey. JEMS 2001 annual report on EMS operational & clinical trends in large, urban areas. *JEMS* 2002; **27:** 46–70.

79 Bashford C, Veenema M. Tele-collaboration in EMS communications: new concepts & technology challenge EMS systems to think outside the box for communications. *JEMS* 2002; **27:** 82–86.

80 Houston TK, Ray MN, Crawford MA, Giddens T, Berner ES. Patient perceptions of physician use of handheld computers. *AMIA Annu Symp Proc* 2003; 299–303.

81 Gaertner J, Elsner F, Pollmann-Dahmen K, Radbruch L, Sabatowski R. Electronic pain diary: a randomized crossover study. *J Pain Symptom Manage* 2004; **28:** 259–67.

82 Magos A, Sharma M, Buck L. Handheld computers in clinical practice: are useful in informing and educating patients. *BMJ* 2004; **328:** 1565.

83 E-diaries help migraine sufferers predict attacks. *Healthcare Benchmarks Qual Improv* 2003; **10:** 71–72.

84 Gross TM, Kayne D, King A, Rother C, Juth S. A bolus calculator is an effective means of controlling postprandial glycemia in patients on insulin pump therapy. *Diabetes Technol Ther* 2003; **5:** 365–69.

85 Kerkenbush NL. A comparison of self-documentation in diabetics: electronic versus paper diaries. *AMIA Annu Symp Proc* 2003; 887.

86 Chang BL, Omery A, Mayo A. Use of personal digital assistants by adolescents with severe asthma: can they enhance patient outcomes? *AACN Clin Issues* 2003; **14:** 379–91.

87 Farzanfar R, Finkelstein J, Friedman RH. Testing the usability of two automated home-based patient-management systems. *J Med Syst* 2004; **28:** 143–53.

88 Kwak M, Han SB, Kim G, et al. The knowledge modeling for chronic urticaria assessment in clinical decision support system with PDA. *AMIA Annu Symp Proc* 2003; 902.

89 Agency for Healthcare Research and Quality (AHRQ). Quit smoking: consumer interactive tool. http://pda.ahrq.gov/consumer/qscit/qscit.htm (accessed July 1, 2005).

90 Hart T, O'Neil-Pirozzi T, Morita C. Clinician expectations for portable electronic devices as cognitive-behavioural orthoses in traumatic brain injury rehabilitation. *Brain Inj* 2003; **17:** 401–11.

91 Anderson P, Jacobs C, Rothbaum BO. Computer-supported cognitive behavioral treatment of anxiety disorders. *J Clin Psychol* 2004; **60:** 253–67.

92 Schulze H. MEMOS: a mobile extensible memory aid system. *Telemed J E Health* 2004; **10:** 233–42.

93 Hanada E, Sobajima Y, Matsumura K, et al. A rapid speech synthesizing software on a PDA for Japanese with speech impairments. *IEEE Trans Neural Syst Rehabil Eng* 2003; **11:** 386–91.

94 Esakof DD. Use of a personal digital assistant for viewing echocardiograms. *J Am Soc Echocardiogr* 2004; **17:** 298.

95 Reponen J, Ilkko E, Jyrkinen L, et al. Initial experience with a wireless personal digital assistant as a teleradiology terminal for reporting emergency computerized tomography scans. *J Telemed Telecare* 2000; **6:** 45–49.

96 Raman B, Raman R, Raman L, Beaulieu CF. Radiology on handheld devices: image display, manipulation, and PACS integration issues. *Radiographics* 2004; **24:** 299–310.

97 Jamison RN, Gracely RH, Raymond SA, et al. Comparative study of electronic *vs* paper VAS ratings: a randomized, crossover trial using healthy volunteers. *Pain* 2002; **99:** 341–47.

98 Wang DH, Kogashiwa M, Ohta S, Kira S. Validity and reliability of a dietary assessment method: the application of a digital camera with a mobile phone card attachment. *J Nutr Sci Vitaminol (Tokyo)* 2002; **48:** 498–504.

99 Sellors JW, Hayward R, Swanson G, et al. Comparison of deferral rates using a computerized versus written blood donor questionnaire: a randomized, cross-over study [ISRCTN84429599]. *BMC Public Health* 2002; **2:** 14.

100 Varkevisser M, Kerkhof GA. 24-hour assessment of performance on a palmtop computer: validating a self-constructed test battery. *Chronobiol Int* 2003; **20:** 109–21.

101 Liao WY, Lee YG, Huang CY, Lin HY, Weng YC, Chou TC. Telemetric electrochemical sensor. *Biosens Bioelectron* 2004; **20:** 482–90.

102 Siegel J. Active ECG. http://www.activecenter.com (accessed July 1, 2005).

103 Vivometrics Corporation. Vivometrics lifeshirt. http://www.vivometrics.com/site/system_howitworks.html (accessed July 1, 2005).

104 Barton J. 20 000 handhelds deployed for clinical trials. http://www.palminfocenter.com/view_story.asp?ID=7635 (accessed July 1, 2005).

105 Centers for Medicare and Medicaid Services (CMS). CMS information security. http://www.cms.hhs.gov/it/security/References/ps.asp (accessed July 1, 2005).

106 Chen D, Soong SJ, Grimes GJ, Orthner HF. Wireless local area network in a prehospital environment. *BMC Med Inform Decis Mak* 2004; **4:** 12.

107 Frenzel JC. Data security issues arising from integration of wireless access into healthcare networks. *J Med Syst* 2003; **27:** 163–75.

108 Tri JL, Trusty JM, Hayes DL. Potential for personal digital assistant interference with implantable cardiac devices. *Mayo Clin Proc* 2004; **79:** 1527–30.

109 Crelinsten GL. The intern's palmomental reflex. *N Engl J Med* 2004; **350:** 1059.

110 Weissman JS. Uncompensated hospital care. *N Engl J Med* 2005; **352:** 1171–73.

111 Brown E, Holmes B. Healthcare IT's next big market. http://www.forrester.com (accessed Dec 1, 2004).

112 Tessier C. An introduction to Mobile Healthcare Alliance (MoHCA) and mobile health. http://www.mohca.org/presentations/MoHCAintro0103.pdf (accessed July 1, 2005).

113 Lindberg DAB, Humphreys BL. 2015—the future of medical libraries. *N Engl J Med* 2005; **352:** 1067–70.

114 Toffel MW, Horvath A. Environmental implications of wireless technologies: news delivery and business meetings. *Environ Sci Technol* 2004; **38:** 2961–70.