electronic Journal of Health Informatics
www.eJHI.net
2011; Vol 6(4):e36

Informatics Innovation in Clinical Care: A Visionary Scenario for Dentistry

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Abstract
Health information technology (HIT) is one of the most significant developments in health care in recent years. However, there is still a large gap between how HIT could support clinical work versus how it does. In this project, we developed a visionary scenario to identify opportunities for improving patient care in dentistry. In the scenario, patients and care providers are supported by a ubiquitous, embedded computing infrastructure that captures and processes data streams from multiple sources. Practical decision support, as well as automated background data processing (e.g., to screen for common conditions), helps clinicians provide quality care. A holistic view of clinical information technology (IT) focuses on supporting clinicians and patients in a user-centered manner. While clinical IT is still in very much a work in progress, scenarios such as the one presented may be helpful to keep us focused on the possibilities of tomorrow, not on the limitations of today.

Keywords: dental informatics; clinical decision support systems; 3d imaging; patient-centered care; medical records systems, computerized; biometry; user-centered design

1 Introduction

Worldwide, health information technology (HIT) is emerging as one of the most significant developments in healthcare in the late 20th/early 21st century. While several countries have been pursuing national HIT infrastructures for some time, the US recently began to make significant investments in this area [1,2]. Over time, several reports have called for computer-based patient records (CPRs) to become a more useful and effective tool to support clinical care than paper records are [3,4].

The clinical care process and how to support it with technology has been intensively studied in biomedical informatics. The oft-cited gap between what clinicians need and what today's HIT systems provide may be primarily due to the difficulty of understanding the complexities of clinical work, rather than a lack of motivation or skill to address them. However, it may occasionally be helpful to envision what perfect (or near-perfect) technology support for clinical practice could look like.

In dentistry, Preston [5] and Sittig et al. [6] have developed such forward-looking visions. In 1996, Preston articulated his vision for "the practice of dentistry, year 2005" in the context of the exponential growth of processor speeds and computing power. He claimed that "in ten years, there should be no restriction on dental computing relative to the technology that will be available." He continued to describe a care environment in which information technology (IT) supported clinical work in an ergonomic and efficient fashion. Local and wide-area networks served to communicate patient information seamlessly; voice input and other technologies facilitated data entry; sensors, as well as intra- and extraoral cameras recorded many types of clinical information; and patients received copies of their electronic records at home. A national database of dental diagnoses, treatments and outcomes served as a central base of evidence for many clinical decisions. Virtual patient records were fully electronic.

In 2003, Sittig et al. followed up with a view that focused on grand challenges in dental informatics. In their scenario, the patient had access to a personal electronic medical and oral health record, which she authorized her dentist to view. Automated clinical data capture was complemented by salivary, crevicular fluid, and other protein and gene microassays. The computer helped the clinician develop a treatment plan supported by best clinical evidence. An information prescription for the patient included referrals to patients who had undergone similar treatment. The dentist took advantage of teleconsultation and surgical simulation technology to provide patient care.

While some of Preston's and Sittig et al.'s prognostications have become reality, we are still far from the vision articulated in either one of those two papers. Yet, periodically revisiting and updating what we think could be possible tomorrow can serve as an important beacon for our work today. With this goal in mind, we conducted a visionary scenario development exercise that is part of the User-Centered Interdisciplinary Concurrent System Design method developed by Carnegie Mellon University [7]. The objective was to identify gaps that exist in using health information technology to improve patient care in dental practice. A secondary goal was to provide a possible framework for clinical informatics research at the Center for Dental Informatics and elsewhere. We present the results in an abbreviated fashion here.

2 Methods

To develop the visionary scenario, we used the following steps: brain-storming; identifying research themes; extracting goals, approach, solutions and metrics to achieve research themes; and, finally, writing visionary scenarios by two competing teams. The brain storming session was attended by experts in various fields and included dentists, dental students and dental auxiliaries, dental informaticians and medical informaticians, human computer-interaction experts and interactive complex system developers. The session generated ideas on the goals of the future HIT; the motivation of using HIT; current issues and barriers to using HIT; approaches and implementation strategies; and, finally, the metrics to be used for evaluation. The session was transcribed and reviewed to identify the major research themes that emerged from the session. The themes were then used by participants to suggest goals, approaches and solutions. Two teams each developed a separate visionary scenario to portray how technologies could be used in dental practice and to obtain user feedback. (We used two separate teams to maximize the breadth and variety of ideas generated.) In the results section, we present a high-level, blended summary of both visionary scenarios and discuss their technology implications.

3 Results

3.1 Scenario

Mary, a 55 year-old administrative assistant, had recently moved to Miami, Florida. One night, she woke up with persistent pain in one of her lower left back teeth. The area had been bothering her for a while, but up to now it only had been uncomfortable when she drank something hot or cold. The next morning, a friend at work recommended Dr. Joseph, a general dentist in her neighborhood. After reviewing the practice Website, Mary decided to see Dr. Joseph as soon as possible.

Mary clicked on the Appointment Tab to request a walk-in appointment for that day. In order to identify herself to the system, she glanced at the Webcam mounted on her computer monitor for a second. EyeID, an iris recognition program, authenticated her and transmitted her Universal Health ID to Dr. Joseph's Website. She briefly described her problem and indicated that she was also interested in comprehensive care, and the system generated a transcript from the video recording. PsychoMetrix, a program designed to measure the psychosocial state of dental patient, generated a read-out of her stress and anxiety level based on an analysis of the voice file. Mary did appear somewhat stressed. Once Mary confirmed the appointment, it was automatically entered on her personal calendar.

Once Mary had made the appointment, Dr. Joseph's practice server retrieved some general information about her previous encounters with healthcare providers, including dentists, through the National Health Information Infrastructure (NHII). Mary had provided the basic set of permissions for the types of health information she would allow Dr. Joseph, or any general dentist, for that matter, to review. She was not too concerned about overly restricting access to her medical information, since she at one time learned that even some antidepressant drugs can have oral side effects. Dr. Joseph's system automatically prepared a summary of Mary's chief complaint and psychometric data, as well as medical and dental histories, and forwarded it to Dr. Joseph's office.

After reviewing the materials later that day, Dr. Joseph ordered a maxillofacial cone beam computed tomography scan for Mary. These scans had become routine when their radiation dose dropped below that of a full mouth series of x-rays. Mary received a "Welcome to our practice" package and the order for the test electronically. She had the scan done that evening and was looking forward to her appointment the next day.

The next morning, Dr. Joseph reviewed the scan together with Mary's other health information. He had quite a few options for interacting with the 3-D model. First, he examined all bone and hard tissue surfaces from the outside. Bone structures appeared to be within normal limits and Dr. Joseph switched to the "teeth only" view. He looked at each tooth separately from all aspects, using the 3-D model, and pre-existing radiographs and photographs. Frankly cavitated lesions were quite obvious and he marked them for possible restoration. He flagged a few incipient lesions for closer clinical inspection. A deeply cavitated carious lesion on #19 seemed to involve the pulp. A computerized analysis of bone density around the apex indicated beginning demineralization, well below the threshold at which even an experienced clinician would have detected it on a radiograph. One of the automated screening tests that Dr. Joseph's electronic dental record (EDR) system performed in the background was to compare Mary's bone density to averages derived from the National Bone and Hard Tissue Database. The test indicated that Mary was currently osteopenic. Dr. Joseph's EDR automatically sent the test results to Mary's primary care physician of record with a request for follow-up.

When Mary arrived in the office the next morning, Eileen, the dental hygienist, greeted her and took her to the operatory. The operatory looked quite high-tech, but in an understated and elegant way. Mary's first impression was that it looked a lot less cluttered than other operatories. Pretty much all devices were portable, had long-term battery power and communicated with each other wirelessly. Mary could see several thin-film, high-resolution input/output devices, for instance the counter surface next to the dental chair. Mary also recognized a digital ink clipboard, whose touch-sensitive high-resolution screen allowed the user to write with a digital pen and rearrange the data by touch.

Eileen had briefly familiarized herself with Mary's record through a high-level overview that was customized to her role as dental hygienist. These days, computer programs were highly task-oriented, customizing the information display and program functions both to the task as well as the person performing it. In addition, the screen display adapted itself to the patient record content, for instance by dedicating a lot more space to the health history for medically compromised patients.

As Eileen conversed with Mary about her chief complaint, previous dental experience, concerns and expectations regarding her current care, and her dietary and behavioral habits, she placed a wireless sensor that looked like a band-aid on Mary's forearm. The sensor measured stress level and vital signs, and transmitted the data to Mary's record continually. The EDR listened in on the conversation, and recorded and updated the record as appropriate. Because Eileen had not asked Mary about changes in her smoking behavior (at the last visit to her physician, Mary had indicated a one-pack/day habit), the EDR reminded her to do so. Before beginning the exam, Eileen briefly verified the data that the computer had generated from the conversation. She found one small error, which she fixed.

The EDR supported Eileen in examining Mary in several ways. First of all, Mary did not have to enter data manually since the computer captured data either directly, or from Eileen's dictation and gestures. Eileen's loupe-glasses, for instance, doubled as a camera which streamed images of the oral cavity to the patient record. Eileen captured key still images by closing her eyes slightly longer when blinking. Periodontal measurements were transmitted wirelessly to the record using a next-generation Florida Probe. DNA probes analyzed Mary's oral flora and gene markers for common diseases. Using a template-driven approach, Eileen spoke findings out loud as she was examining Mary while the computer transcribed them. The template was customized for Mary; thus, the EDR reminded Eileen to check the thyroid because of a familial history of Graves' disease.

After Eileen had finished her examination, she briefly discussed the findings with Mary. She invited Mary to take a closer look at the results on the digital ink clipboard while she went to get Dr. Joseph. The clipboard displayed a summary of findings that was customized for Mary's educational level, previous dental experience and her preferences for level of detail of health information. As she interacted with the data, Mary also reviewed some resources on nutrition provided by SuperMEDLINE, a 3rd generation version of MEDLINEPlus. Mary didn't have time to review all information, but she knew that she could continue right from the point where she had left off on the clipboard once she logged onto her home computer.

After a few minutes, Dr. Joseph introduced himself to Mary. He reviewed Eileen's findings on the clipboard that Mary had used. As soon as he took the clipboard, however, the EDR reformatted the data for the "doctor" view. The main page summarized clearly and concisely the result of the exam Eileen had conducted. In addition, it listed all issues that Eileen had flagged for Dr. Joseph's review.

Dr. Joseph briefly reviewed the findings for #19 and discussed possible treatment approaches and their prognosis. Since Mary had indicated an interest in comprehensive care, Dr. Joseph asked the computer to draft a treatment plan. When he had first heard about this capability, Dr. Joseph thought it was one of the most useless inventions of all time. However, after talking to some colleagues who were using this function, he realized that the program did not create the treatment plan for the dentist, but simply suggested options to consider. In addition to taking patient-specific factors into account, the program also consulted the most up-to-date evidence-based databases, giving Dr. Joseph much more time to evaluate the relative trade-offs of each approach.

Dr. Joseph reviewed the software's suggestions together with Mary. Mary asked whether one of her missing teeth could be replaced by an implant. Dr. Joseph asked the EDR to evaluate that suggestion. The EDR replied that the bone density and geometry in that area were not optimal, and that Mary's smoking habit was a contraindication. Also, as compared to a fixed bridge, the procedure would receive a comparatively low reimbursement from Mary's insurance company. The treatment plan presentation by the EDR also included suggestions for sequencing the procedures, the appointment time required and the expected costs at each stage.

After Mary and Dr. Joseph had settled on a preliminary treatment plan, Dr. Joseph initiated root canal treatment on #19. Fortunately, he had noticed that this tooth had five canals on the 3D model. Therefore, he did not miss the fifth canal clinically, something that would have been very likely had he worked only from a radiograph. Whenever Dr. Joseph worked with indirect vision, his loupe-glasses automatically mirrored the image, presenting the scene as if he was looking at it directly. Thus, as far as he was concerned, Dr. Joseph was still working with direct vision. Since he had started using this system, his preparations in hard-to-see areas had markedly improved. As Dr. Joseph worked, patient documentation was generated almost automatically. Once in a while, he captured a still image of what he was looking at. This came in especially handy when he was replacing restorations placed by other dentists and could view the clinical situation they had seen.

As the appointment ended, he asked Mary if she would like to schedule her next appointment. Mary said she would do it from home that evening, thanked Dr. Joseph for his efforts and headed home.

3.2 Informatics innovation in the scenario

The scenario embodies a mix of current, emerging and future informatics and information technology innovations that illustrate how technology could improve patient care more efficiently and effectively than is currently the case. Below, we discuss some of those innovations and comment briefly about their current state with regard to research and development:

Ubiquitous, embedded computing: In the scenario, a lot of technology is almost invisible because it is embedded in everyday objects or the environment [8]. A normal-looking clipboard is, in reality, a flexible input/output device for digital data. The electronic dental record system acquires data through multiple devices, such as microphones and optical sensors. Current research on ubiquitous computing tends to be focused on acquiring health data about patients [9-11]; however, systems to address the needs of physicians and other caregivers also exist [12].

Embedded computing frees users from having to pay undue attention to the mechanics of operating the technology; instead, it lets them concentrate on the task at hand. Such technology facilitates natural interaction that is not cognitively burdensome. In addition, embedded technology can be used to inform without demanding our focus or attention [13].

Electronic health information infrastructure interfaced with general computing infrastructure: The scenario illustrates the interplay between the health information infrastructure and the patient's computing environment. For instance, when Mary schedules an appointment on Dr. Joseph's Website, the event is automatically entered in her personal calendar. While many countries are pursuing a national health information infrastructure initiative [1,14] and promote, among other technologies, the adoption of personal health records (PHR) [15,16], the integration of these systems with a patient's personal computing environment appears to receive relatively little attention.

Health information technologies, such as hospital information systems and PHRs, tend to be conceptualized as closed systems, mainly due to concerns about confidentiality and security of patient data. However, a truly user-centered philosophy would require that health information systems seamlessly and transparently interoperate with the patient's personal computing environment.

Biometrics, signal and image processing: The scenario is replete with examples of sensing and signal processing, such as using iris recognition for patient identification and methods to monitor some of Mary's physiological parameters. Current research has yielded innovations such as a telemetry system to monitor blood pressure, respiratory rate, body temperature and pulse rate [17]; an "intelligent" toothbrush capable of monitoring brushing motion during toothbrushing to improve patient education and instruction in oral hygiene [18];

and a miniaturized radio frequency identification (RFID) transponder that could be placed in the pulp chamber of an endodontically treated human tooth [19]. Several of these technologies have matured to the degree that their application in many clinical data collection and health monitoring tasks has become feasible.

Automated, semi-continuous data capture and processing of multiple data streams: Clinicians spend a significant amount of effort documenting patient care [20,21]. Not only does this activity require significant time and effort, but the fairly common time delays in documentation can also result in incomplete and incorrect entries [22]. Automated, semi-continuous data capture and processing can help "offload" clinician and staff documentation responsibilities and increase time available for patient care. For instance, automated speech recognition (ASR) using medical natural language processing (MNLP) techniques could potentially extract a structured encounter note from a doctor-patient conversation [23,24]. Recently, we developed and evaluated a semantic representation for information that automatically extracted information from dictated dental exams [24]. Future research areas include multi-speaker ASR and enhancement of MNLP techniques to not only recognize concepts but also fully interpret a two-party conversation.

Automated record and text summarization: Seamless communication of patient information within the healthcare system means that more information is available to each clinician. Since manual review of detailed records is labor-and time-intensive, software applications must become "smart" enough to summarize relevant information in a valid and reliable manner. Researchers are combining information extraction methods and machine learning techniques such as text classifiers and hidden Markov models to extract relevant information from patient documents [25].

Automated data analysis: Where appropriate, automated data analysis can augment the clinician's work by handling "supplemental" clinical tasks (for instance, the osteopenia/osteoporosis screening test in the scenario). In this way, the standard of care for the individual patient is less dependent on individual physician performance and can be enhanced based on best available evidence. Developing automated risk-assessment tools and tailoring clinical guidelines to individual patients using patient predictive models and statistical methods would also enhance patient care and preventive management [26-28].

3D imaging and model construction: 3D imaging and models are examples of new diagnostic and therapeutic approaches of particular relevance for areas in healthcare in which an understanding of spatial structures and relationships is important, such as dentistry [29,30]. Examples of three-dimensional methods that are already being used clinically include 3D surface imaging of extraoral [31] and intraoral surfaces [32], as well as systems that integrate data more than one source [29]. Recent research has added the analysis of dynamic, functional 3D data over time [33]. While base technologies and methods have developed quite rapidly in recent years, we do not yet have good insights as to how 3D representations could improve clinical decision-making [34,35]. In addition, concerns about radiation exposure tend to limit the application of methods using ionizing radiation.

Inferential and decision support considering multiple factors: Decision support is a well-developed application area in informatics research which, demonstrably, and improved practitioner performance and, to a lesser degree, patient outcomes [36]. However, many decision support systems are still highly specialized, narrowly focused and in limited use. One aspect in decision support systems that could be improved is to take a more general approach that considers all relevant inputs for a decision, such as the insurance reimbursement for the implant in the scenario. Decision support algorithms such as artificial neural network could be utilized to analyze patterns in patient data and derive associations between patient information, findings and diagnosis [37].

Workflow support: Electronic patient records typically support selected clinical activities, but rarely the complete workflow. For instance, most EMRs do not support early note taking or transient records. In order to be truly useful, EMRs should support the full life-cycle of data and information, from the scribbles on a napkin to the final discharge summary. Another example of workflow support is computer-based support for the coordination of care, an aspect of HIT which is poorly developed at this time [38,39].

Applications that adapt to content as well as user roles: Part of the power of computing technology derives from the fact that it can represent and display information in a standardized, reproducible manner. However, neither patients nor their caregivers are standardized. In the scenario, data display is often customized to the role of the user, such as the dental hygienist and dentist. Information presentation and interaction that take into account information content and user role could make computers more efficient and effective in supporting clinical work. User models [40,41], which represent some of the characteristics and activities of the user in a machine-processable form, are needed to perform this customization.

Patient-centered, adaptive computing: The idea of patient-centered computing is not new [42,43], but has gained more prominence in recent years as the patient has become an important focus in the design of health information technology [1,10]. Patient-centered customization of information and system interactions has significant potential to tailor care individually and maximize the results of health care interventions. Such customization could take patient health literacy, education level and preferences into account. Studies that have evaluated systems in practice found that patient-centered computing can improve health outcomes and patient satisfaction [44,45].

4 Discussion

The presented scenario and its technology implications represent only one possible view of the future of clinical technology application in dentistry specifically and healthcare generally. However, in our view it highlights general principles that are important in making technology more useful to clinicians and patients than is currently the case.

First, the future vision for HIT should focus not only on the healthcare context, but also on the general computing context of patients and caregivers. Ubiquitous acquisition and transmission capabilities for health information should be used to gather information from (e.g. monitoring of health parameters in daily life) or transmit information to wherever appropriate (e.g. sending care appointments to a patient's personal calendar). Second, ubiquitous computing presents a significant opportunity to embed information technology and informatics into the existing work context of the clinician (or life context of the patient), and make interaction with computers more natural, unobtrusive and efficient. As many future-oriented initiatives in ubiquitous computing and augmented reality have shown, computer technology can be embedded productively in many everyday objects and artifacts. For example, the electronic clipboard may help normalize a physician-patient relationship that is often disturbed by current, more intrusive technology. In this way, embedded computing in healthcare may live up to Weiser's vision: "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" [8].

Lastly, it may be time to relinquish the view of the clinician as the sole "information processor" and decision maker in healthcare. Clinical technology has begun to produce data in volumes that can not be exhaustively processed by our human-based healthcare system. Not only can computers help clinicians with routine, determinate decisions and novel analyses; allowing them to do so will also free up caregivers for making the types of higher-level, complex decisions that humans currently perform much better than computers. However, despite computational feats such as IBM's Jeopardy-playing (and –winning) Watson computer, medical human-level intelligence is still far off for computers. In the meantime, we should focus our energies on designing computer systems that provide optimal cognitive support for medical decision-making, as suggested by a recent National Research Council report [3].

In terms of technical feasibility, our scenario combines several current, emerging and future technologies. Implementers of health information technology must focus on what is technically possible at a given point in time in order to deliver working systems. However, at the same time system architectures and designs need to be adaptable and flexible enough to grow with the evolution of technology and to accommodate new paradigms.

5 Conclusion

Many visions for the future of technology in clinical care have been articulated in the literature. Despite the significant developments and achievements since the beginning of the computer revolution, clinical computer technology is still in very much a work in progress. Engaging in periodic "visioneering" may be helpful to keep us focused on the possibilities of tomorrow, not the limitations of today. Many of the technological opportunities discussed in this paper will require significant research and development efforts. Therefore, our purpose in writing this paper was only partially to try to predict what will be. Our main goal, rather, was to stimulate colleagues and the community to realize the future through practical, hands-on research. We hope that in this way, our paper makes a small contribution to building a future for clinical technology that benefits patients, providers and society.

6 Acknowledgements

We gratefully acknowledge the contribution of the visionary scenario session participants, including Claudio M. Levato, DDS; Bruce Parker, DDS; Ms. Stephanie Jeffreys, Practice Administrator; Dale Miles, DDS, MS; Michael Spring, PhD; Greg Cooper, MD, PhD; Heiko Spallek, DMD, PhD; Humberto M. Torres-Urquidy, DDS, MS; Jeannie Irwin, MS, PhD; and Andrew Martin and Grady Shaver, pre-doctoral dental students. In addition, we thank the writing teams of the visionary scenarios, as well as Michael Dziabiak for his help with preparing this manuscript.

The development of this manuscript was supported by grants 1 KL2 RR024154-02 from the National Center for Research Resources (NCRR) and 5T15LM07059-17 from the National Library of Medicine (NLM). Its contents are solely the responsibility of the authors and do not necessarily represent the official view of NCRR or NIH.

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