Research Paper ■

Clinical Computing in General Dentistry

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Abstract **Objective:** Measure the adoption and utilization of, opinions about, and attitudes toward clinical computing among general dentists in the United States.

Design: Telephone survey of a random sample of 256 general dentists in active practice in the United States.

Measurements: A 39-item telephone interview measuring practice characteristics and information technology infrastructure; clinical information storage; data entry and access; attitudes toward and opinions about clinical computing (features of practice management systems, barriers, advantages, disadvantages, and potential improvements); clinical Internet use; and attitudes toward the National Health Information Infrastructure.

Results: The authors successfully screened 1,039 of 1,159 randomly sampled U.S. general dentists in active practice (89.6% response rate). Two hundred fifty-six (24.6%) respondents had computers at chairside and thus were eligible for this study. The authors successfully interviewed 102 respondents (39.8%). Clinical information associated with administration and billing, such as appointments and treatment plans, was stored predominantly on the computer; other information, such as the medical history and progress notes, primarily resided on paper. Nineteen respondents, or 1.8% of all general dentists, were completely paperless. Auxiliary personnel, such as dental assistants and hygienists, entered most data. Respondents adopted clinical computing to improve office efficiency and operations, support diagnosis and treatment, and enhance patient communication and perception. Barriers included insufficient operational reliability, program limitations, a steep learning curve, cost, and infection control issues.

Conclusion: Clinical computing is being increasingly adopted in general dentistry. However, future research must address usefulness and ease of use, workflow support, infection control, integration, and implementation issues.

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Computer-based patient records (CPRs) are increasingly being adopted in primary care.[1] According to a recent review, approximately 20% to 25% of physician offices in the United States use CPRs,[2] and between 50% and 60% will do so in the near future. While many studies have reported that CPRs can improve procedural aspects of care delivery,[3] the effects of CPRs on patient outcomes are equivocal.[3,4] Nevertheless, adopting CPRs in primary care and other health care settings is seen as a key factor in improving the quality of health care in the United States.[5]

As a primary care discipline with approximately 137,000 active practitioners in the United States,[9] general dentistry has become increasingly computerized in the past 20 years. As Figure 1 shows, the proportion of all dental offices (generalists and specialists) with computers has increased from 11% in 1984 to over 85% in 2000. According to data from the Dental Products Report (DPR), a dental trade publication, the adoption of computers in treatment rooms follows a similar curve with a time lag of approximately 13 to 15 years. The 2004 Survey on Computer/Internet Usage by the DPR found that 30% of all general dentists used computers in the operatory [an operatory is a treatment room or bay equipped with a dental chair].[10] Respondents' primary uses for computers at chairside included scheduling (77.9%), treatment planning (63.9%), patient education (60.7%), hard tissue charting (58.2%), and periodontal charting (54.1%). (The data were collected in a mail survey of 2,000 DPR subscribers with a single mailing that had a 20.4% response rate.)

In 2003, Clinical Research Associates conducted a comprehensive survey about dental office management software.[11] The survey determined the market share of dental systems

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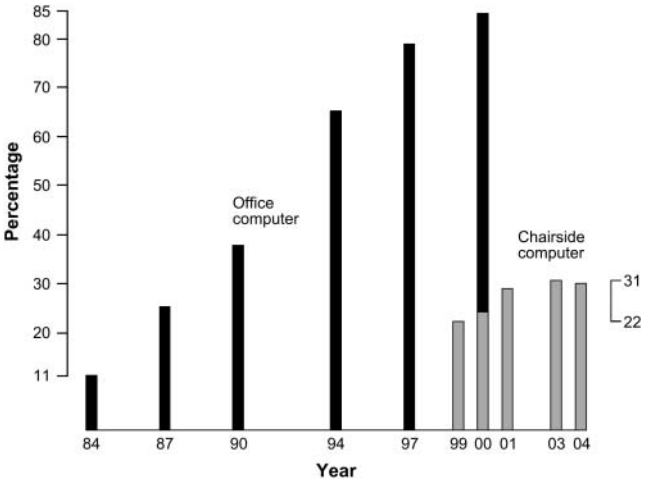

Figure 1. Percentage of all dentists who have a computer in their office (1984 to 2000 American Dental Association surveys[6–8]) and percentage of general dentists who have a computer at chairside (1999 to 2004; data provided by the Dental Products Report [DPR] [Gail Weissman, personal communication, 2005). (DPR data were obtained through a mail survey [single mailing without follow-up] of subscribers to the DPR. Sample sizes and response rates were as follows: 1999: 5,000/19.1%; 2000: 5,000/15.8%; 2001: 2,000/12.2%; 2002 and 2003: no information available; 2004: 2,000/20.4%.)

as well as qualitative data including software applications' strengths and weaknesses, features rated satisfactory and unsatisfactory, features used and desired, and positive and negative experiences. The top five systems in terms of market share were Dentrix (26.2%) and Easy Dental (9.8%) (both from Dentrix Dental Systems, American Fork, UT), SoftDent (15.0%) and PracticeWorks (7.9%) (both from Kodak Corp., Rochester, NY), and EagleSoft (11.0%) (Patterson Dental, St. Paul, MN). Commonly mentioned strengths of the software applications included easy to use/learn, scheduling, integration and flexibility; weaknesses included none, complexity, and integration.

Implementing clinical computing in a dental office is a difficult undertaking for a number of reasons. Most dental offices are small (75.3% of all dentists work in a solo practice)[12] and thus cannot spend large amounts of capital on information technology (IT). Limited personnel resources require that most dentists outsource the installation and maintenance of the IT infrastructure to a vendor or consultant. Dental computer applications are complex because they must integrate and maintain structured data (such as intraoral findings, treatment plans, and the medical/dental history), free text (such as progress notes), images (such as radiographs and photographs), and three-dimensional models.[13] On a small scale, these systems integrate the functions that are typically found in medical software applications for registration, admission, discharge, and transfer; laboratory results; picture archiving and communications; computer-based patient records (CPRs); and billing and insurance processing. Currently, different companies supply the necessary software and hardware components, which makes integration a significant challenge for end users.[14]

While several surveys[6–8,10] have established basic measures of the adoption of computers in dental practice, no detailed investigation into the adoption and use of, opinions about, and attitudes toward clinical computing among general dentists in the United States has been reported. Our specific goals were to determine demographic and practice characteristics of dentists who use computers clinically; the information technology infrastructure in their practices; the method of storage (paper and/or computer) for clinical information; data entry responsibilities and modalities; opinions regarding advantages and disadvantages of, and barriers, enablers, and potential improvements; clinical use of the Internet; and opinions about the proposed National Health Information Infrastructure (NHII).

Methods

A comprehensive literature review did not identify any validated survey instruments that our study could have used. We began by brainstorming the concepts we wanted to cover, such as IT infrastructure, storage and recording of clinical information, and clinical Internet use. Several semistructured interviews with dentists helped to define and narrow the survey concepts further, and the research group formulated a draft survey. The survey was then pilot-tested; we made minor modifications and corrections as a result. The final survey and the research protocol were submitted to the Institutional Review Board, which classified the study as exempt under section 45 CFR 46.101(b) (2) (University of Pittsburgh IRB number 0310076).

The survey consisted of 39 questions grouped into six categories. (The full survey is available online at http://di.dental.pitt.edu/clinical-computing-survey-2004.) The categories included practice characteristics and IT infrastructure (e.g., number of dentists and auxiliary personnel, number of operatories availability of computers in clinical areas and clinical software applications used); clinical information storage (paper-/computer-based storage of common clinical information categories such as chief complaint, medical history, intraoral findings, images, and treatment plan); data entry and access (e.g., data entry responsibilities, use of alternative input devices such as voice and touch screen, and access points for clinical information); attitudes toward and opinion of clinical computing (e.g., good/bad features of the software in use and barriers, enablers, and possible improvements for clinical computing); clinical Internet use (e.g., access of clinical information on the Internet and use of e-mail with patients); and the National Health Information Infrastructure (NHII) (e.g., expected utility of the NHII in dentistry). Demographics were not included in the survey questions since those data were already available for the sample.

In this study, clinical computing refers to computing applications of any kind that are used in the context of providing clinical care. While a similar research project in medicine might have focused on the CPR, we did not do so for two reasons. Most dentists and auxiliary personnel are relatively unfamiliar with the term CPR. In addition, clinical computing in dentistry is broader than CPR since it includes not only the practice management system (PMS), which stores and manages clinical data, but also specialized clinical devices such as CAD/CAM milling machines and digital radiology sensors. We therefore referred to chairside computers or chairside computing during the interviews, terms that were easily understood by the participants.

We conducted the study by telephone instead of by mail or e-mail for several reasons. Since no in-depth studies of clinical computing in dentistry have appeared in the literature, we assumed that most participants would be quite unfamiliar with being surveyed on this topic. A telephone survey gave us the opportunity to explain questions that the participant did not understand or to ask the participant to elaborate if an answer was not clear. Second, many questions solicited information about experiences and attitudes that did not seem well suited to a written response. Last, the telephone survey allowed us to branch the survey in real time, eliminating sections that did not apply to the particular respondent.

All the authors with the exception of JY (two faculty and three postdoctoral students) served as telephone interviewers. The University Center for Social and Urban Research (UCSUR) at the University of Pittsburgh trained the graduate students (TT, PH, and MTU) in telephone interviewing using internal training manuals as well as *Survey Research Methods* by Floyd Fowler[15] and *Mail and Telephone Surveys: The Total Design Method* by Donald Dillman.[16] The students performed mock interviews in the UCSUR laboratory and conducted several practice interviews with dentists. The faculty were trained through phone consultations with UCSUR and several practice interviews with dentists. The practice interviews lasted between 15 and 25 minutes.

To obtain a sample of eligible participants for the study, we first screened a random sample of 1,159 general dentists in the United States. We obtained a sample from the American Dental Association (ADA) that met our first inclusion criterion, general dentists in active practice. UCSUR telephone interview staff then screened this sample for our second inclusion criterion by asking whether the office had a computer, and if so, whether at least one computer was being used in the treatment area(s). If both responses were affirmative, the participant was eligible for the study. The interviewer indicated that the office would receive a letter about the study and obtained the operating hours to facilitate scheduling of the interview. Mailing introductory letters prior to phone surveys can increase the response rate.[17]

Approximately three weeks after mailing the letter about the study, one of the interviewers called the office to obtain consent to participate in the study and to schedule an interview with the dentist. Our goal was to interview the dentist whose name was listed in the ADA sample, but we made two exceptions. If the listed dentist was not available, but a colleague in the same office was, we interviewed the colleague. Second, if only auxiliary personnel (such as dental hygienists and dental assistants), and not the dentist, used the computer for clinical purposes, we interviewed the most knowledgeable auxiliary. (Questions that applied only to dentists were deleted from the auxiliary interviews.) Interviewers made up to four follow-up calls attempting to schedule an interview. The initial sample was screened in January 2004, and all interviews were completed between January and December 2004.

The data collected in the interviews was recorded on a paper form by the interviewer and initially a note taker. Once it became clear that a separate note taker did not capture any more information than the interviewer alone, interviewers began to work independently. As soon as possible after the interview, typically within 24 hours, the data were entered into an Access database (Microsoft Corporation, Redmond, WA) and checked for accuracy. At the conclusion of the study, answers to closed-ended questions were summarized through descriptive statistics. Answers to open-ended questions were reviewed manually, classified into categories, and totaled. In the results, we report the number of respondents for each question, since not all participants answered all questions. We compared categorical data (such as gender and race) using chi-square tests, age using analysis of variance (for the nonrespondent analysis), and proportions using the z-test with Yates correction.

Results

The screening sample of 1,159 participants included 256 respondents (24.6%) with computers at chairside, 647 (62.3%) with computers elsewhere in the office, 136 (13.1%) without a computer, and 120 (10.4%) nonrespondents. (The results are adjusted for respondents who, during the screening interview, incorrectly indicated that they used computers at chairside.) Thus, 86.9% of the initial sample (n = 1,039) used a computer in their practice. There is no statistically significant difference between this result and the national average of 85.1%[6] among all dentists (z-test with Yates correction; z = 1.38). Of the 256 dental offices that met the inclusion criteria, we successfully interviewed 102 (39.8%). The respondents included 88 dentists and 14 auxiliary personnel. The response rate for the screening phase was 89.6% and 39.8% for the interview phase. Interviews lasted on average 21 minutes, with a standard deviation of nine minutes.

Practice Characteristics and Information Technology Infrastructure

The mean age of the dentists who responded (n = 102) was 50 years (standard deviation: 10 years). Eighty-four percent of them were male and 16% female. Fifty-seven percent of the respondents were white and 9% belonged to other ethnic groups. (No information was available for 34%.) No significant differences were found when we compared respondents' and nonrespondents' age ($F_{1,219} = 2.4$, $p > 0.1$), gender ($\chi^2 = 0.69$; $df = 1$; $p > 0.4$), race ($\chi^2 = 2$; $df = 4$; $p > 0.7$), and geographic area of the practice ($\chi^2 = 7.98$; $df = 8$; $p > 0.4$).

Forty-five percent of respondents worked in a solo practice and 55% in a group practice compared to the national average of 73% and 27%,[9] respectively (Table 1). The difference between the distribution of practices with one, two, and three or more dentists was statistically significant ($\chi^2 = 62.57$; $df = 2$; $p < 0.0001$).

Group practices with four or more dentists were relatively rare in our sample. Smaller practices (fewer than four dentists) on average employed a similar number of dental

Table 1 ■ Distribution of Dental Practices in Terms of the Number of Dentists and the Average Number of Dental Hygienists, Dental Assistants, and Operatories

No. of Dentists	% of Sample	National Average[12]	Avg. No. of Hygienists	Avg. No. of Assistants	Avg. No. of Operatories
1	45.1	73.3	1.8	1.8	4.2
2	26.5	18.2	2.5	2.9	5.3
3	17.6	8.5	3.8	3.9	7.6
4	3.9		2.3	4.3	7.8
5+	6.9		6.4	10.0	12.6

hygienists and assistants, while larger practices used proportionally more assistants. The number of operatories ranged from an average of 4.2 operatories in solo practices to an average of 12.6 operatories in practices with five dentists or more. In 85% of the practices, all operatories were computerized; in the remainder, respondents cited low/no use of certain operatories, cost, space, and other factors as reasons for not equipping all operatories with a computer. In 92% of the practices, all operatory computers were networked. Exceptions were practices with single computers and terminal-based systems.

Typically, all dentists and auxiliary staff were involved in clinical computing in the practices that responded to our survey. Fifty-eight percent (n = 85) of the responding dentists had taken a computer course, and 34 (42%) respondents rated themselves as "very comfortable," 38 (47%) as "comfortable," nine (11%) as "not very comfortable, and none as "not at all comfortable" with computers.

One of four practice management systems was in use in 80% (n = 101) of all practices: Dentrix (Dentrix Dental Systems, American Fork, UT) in 40%, Eaglesoft (Patterson Dental, St. Paul, MN) and SoftDent (Kodak Corp., Rochester, NY) in 15% each, and PracticeWorks (Kodak Corp., Rochester, NY) in 10%. The remaining 20% of respondents used one of 13 other practice management systems. Seventy percent of the participants (n = 102) used at least one other clinical software application, for instance, for digital radiology, digital photography (intraoral, extraoral, or both), and Invisalign (a recently developed method of orthodontic treatment).

Seventy-seven percent of the respondents (n = 102) used the computer for patient education. Forty-four percent of those used Casey (Patterson Dental, St. Paul, MN), a widely adopted stand-alone patient education program; 22% the patient education module of Dentrix, SoftDent, and Eaglesoft, respectively; 4% PowerPoint; and 11% another software application. (Twenty-four percent did not specify the application they used. Percentages add up to slightly more than 100 because four respondents used more than one application.) Patient interaction with the computer, either for patient education purposes or entering the medical/dental history, was limited; only 5% of the practices (97 respondents) allowed patients to interact with a computer.

Clinical Information Storage

A particular focus of this survey was the degree to which clinical, as opposed to administrative, information about patients was stored on the computer and on paper. Figure 2 shows the distribution of 12 common clinical information categories across paper- and computer-based storage. The first three information categories, appointments, treatment plans, and completed treatment, have a strong connection to office operations and billing and thus are stored on the computer in the overwhelming majority of practices (97%, 97%, and 92%, respectively) (n = 100). The oral health status (often equated with intraoral charting) (71%), intra-/extraoral images (69% and 67%, respectively), diagnoses (57%), radiographs (56%), and the dental history (55%) follow in terms of frequency of computer-based storage. Medical history and progress notes (both 49%) and the chief complaint (45%) tend to be stored on the computer least often.

The relatively large amount of paper-based information duplicated on the computer should be noted. Several respondents mentioned that they were slowly transitioning to paperless systems and wanted to make sure that computer-

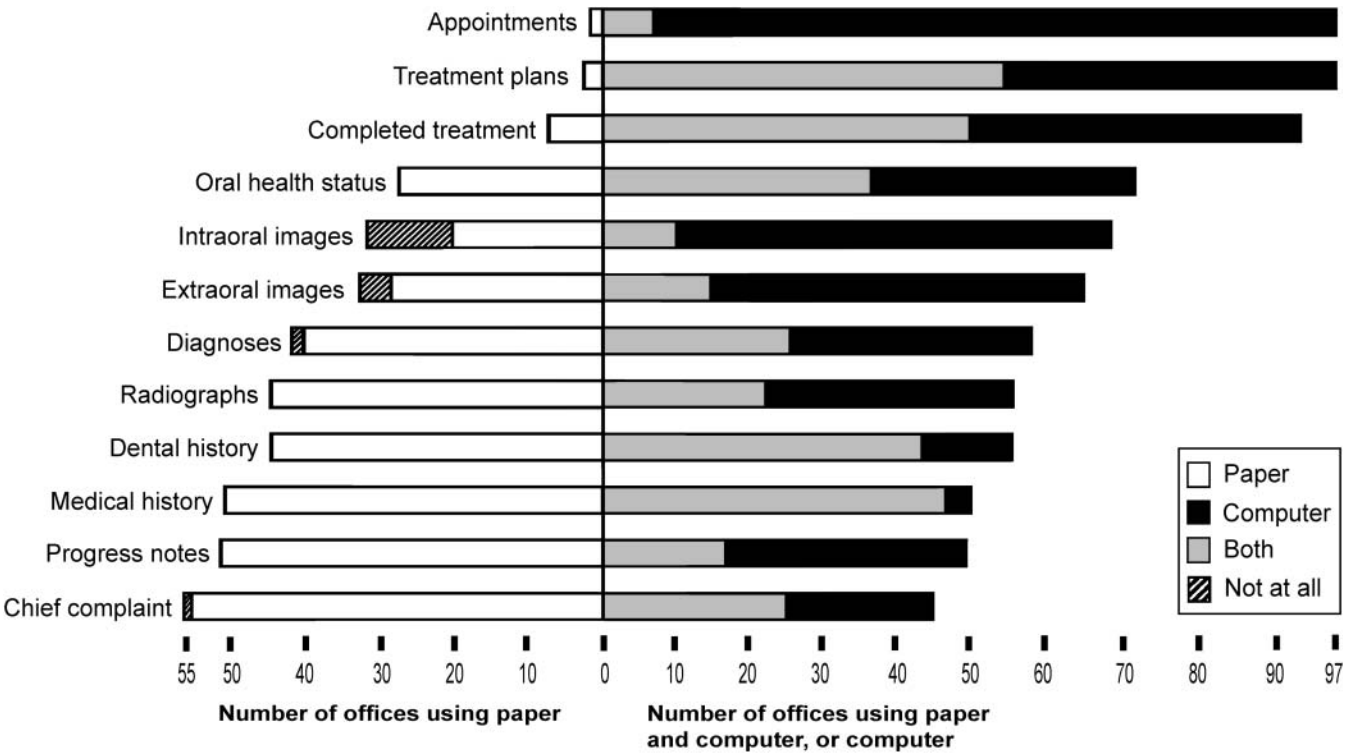

Figure 2. Storage of major clinical information categories on paper/computer, sorted by utilization of computer-based storage in descending order (Paper = information stored only on paper; Computer = information stored only on the computer; Both = information on paper duplicated on the computer; Not at all = information not recorded at all).

Table 2 ■ Dentists', Hygienists', Assistants', and Front Desk Personnel's Participation (Percentage) in Entering Data in the Respective Information Category

	% of Individuals Participating in Data Entry			
Information Category	Dentists	Hygienists	Assistants	Front Desk
Progress notes	40	31	25	5
Extraoral images	36	26	35	2
Intraoral images	35	27	36	2
Diagnoses	32	29	32	7
Treatment plan	27	25	31	17
Chief complaint	23	23	32	22
Completed treatment	23	28	31	19
Oral health status	21	37	36	6
Dental history	20	30	40	11
Radiographs	16	34	48	2
Medical history	13	21	29	36
Appointments	6	27	24	43
Total	23	28	33	16

The analysis includes only practices (n = 88) employing at least one hygienist, assistant, and front desk person.

based patient records were reliable and secure before phasing out paper. Nineteen respondents maintained completely paperless practices, which equates to 1.8% of all general dentists (standard error of the proportion = 0.4%).

Data Entry and Access

Entering data into the computer is difficult for dental personnel who work directly with the patient. The Centers for Disease Control and Prevention recommend the use of personal protective equipment (PPE)[18] such as gloves and face masks for infection control during clinical care. When wearing PPE, dentists and other clinical personnel should not touch devices that cannot be disinfected or sterilized. As this is the case with a standard keyboard and mouse, dental hygienists and assistants, who do not wear PPE at the time, commonly enter data for the dentist. Table 2 shows who (dentist, hygienist, assistant, and/or front desk personnel) participates in entering data in each one of 12 clinical information categories. (The analysis includes only practices employing at least one hygienist, assistant, and front desk person [n = 88].) Values are standardized to 100% in each information category and only express the participation in, not the relative workload of, entering information.

Dentists tend to be particularly active in entering progress notes and diagnoses and in recording extra- and intraoral images. Compared to other personnel, they participate relatively little in recording oral health status, dental history, radiographs, medical history, and appointments. Hygienists and assistants are active in data entry in all categories, particularly the oral health status and radiographs. Front desk personnel primarily enter data that are either captured at the beginning of the appointment, such as the chief complaint and the medical history, or have a strong connection to predetermination and billing, such as treatment plans and completed treatment. As expected, front desk personnel lead in entering appointments. Dentists' overall participation in data entry is 23%, hygienists' 28%, assistants' 33%, and front desk personnel's 16%.

Two input methods that facilitate data entry by personnel wearing PPE are voice and touch screen. Several dental software packages offer either one or both of these input methods as an option. As Table 3 shows, 13% of the respondents each used voice and/or touch screen. (Three respondents used both.) While only 3% had tried to use a touch screen and abandoned it, 16% had done so with voice input. Participants discontinued the use of voice because of problems with speech recognition, lower efficiency compared to other data entry methods, and incompatibilities. Other than voice and touch screen, a small fraction of respondents used specialized input devices, such as barcode scanners and electronic periodontal probes.

Table 3 ■ Number of Respondents Using Voice and/or Touch Screen as Input Devices

	In Use	Tried and Discontinued	Never Considered
Voice (n = 99)	13%*	16%	71%
Touch screen (n = 97)	13%*	3%	84%

*Three practices used both voice and touch screen, and are included in both totals.

The primary location for interacting with clinical data for all our respondents was the dental operatory. However, 93% (n = 99) (n = 100) also accessed patient data from elsewhere in the office (such as a consultation room), 37% (n = 84) from home, and 16% (n = 79) from a personal digital assistant.

Attitudes toward and Opinions about Clinical Computing

Most of the respondents adopted computers in the clinical environment relatively recently. As Figure 3 shows, about 20% (n = 99) of the respondents adopted a computer at chairside between 1985 and 1994, while the remaining 80% did so between 1995 and 2003. Figure 3 also suggests that adoption may have accelerated beyond the initial phase of slow growth typical in technology diffusion.[19]

The reasons for adopting computers at chairside (Table 4) fell into three categories: office efficiency and operations, diagnosis and treatment, and patient communication and perception. The top three reasons for adoption were improved data management, such as direct entry of treatment plans and appointments; digital imaging, primarily digital radiology; and improved efficiency, for instance, through scheduling directly in the operatory.

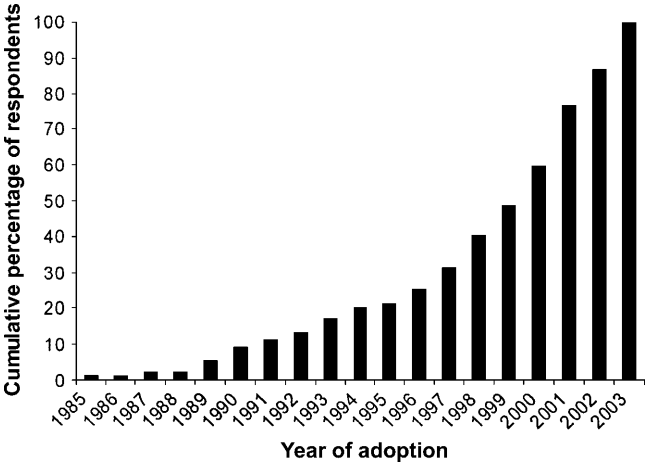

Figure 3. Year of adoption of chairside computing and cumulative percentage of respondents (n = 99).

Table 4 ■ Reasons for Adopting Chairside Computing Sorted by the Number of Mentions

Category	Reason	No. of Mentions*	%†
Office efficiency and operations	Improved data management (e.g., direct entry of treatment plans and appointments)	47	28
	Improved efficiency (e.g., scheduling in the operatory)	26	15
	Minimize front desk congestion	10	6
Diagnosis and treatment	Digital imaging, intraoral charting	29	17
		10	6
Patient communication and perception	Use current technology	17	10
	Patient education	10	6
Other		19	11

*Respondents could mention more than one reason (n = 98).
†Error due to rounding.

We also surveyed respondents on the features of their practice management systems that they liked and disliked as well as the perceived barriers to and the advantages and disadvantages of computers at chairside. Table 5 shows the categorized answers to the corresponding open-ended questions.

Many participants mentioned charting, treatment planning, imaging, and scheduling as features that they liked in their respective PMS. Over one fourth of respondents could not identify anything in their PMS that they disliked. Deficits in functionality and usability were two of the aspects most disliked in PMSs, followed by charting and the inability to customize. Insufficient operational reliability (such as crashes), functional limitations in the software, the learning curve, cost, and infection control issues were cited as major barriers. Several of these qualitative findings are mirrored in a 2003 survey of practice management systems by Clinical Research Associates.[11] Participants derived a number of advantages from computers at chairside, including improved efficiency, information access, patient education, organization, and imaging. Over 30% of respondents could not identify any disadvantages. Insufficient operational reliability, cost, infection control issues, and insufficient usability emerged as the most often-cited disadvantages.

Thirty-seven percent of respondents (n = 94) cited input mechanisms as the most important area for improvement. Fifty-seven percent of those individuals specifically mentioned the need for better voice interfaces, and 24% for improved touch screens. Fifteen percent of the respondents would like to see smaller computing equipment for the operatory. Other suggested improvements included better user interface design, faster computers, improved digital radiology, and wireless technology.

Clinical Internet Use

The vast majority of respondents had Internet access in their offices (94%; n = 99 respondents). DSL predominated as connection method (46%; n = 89), followed by dial-up (31%), cable modems (17%), and other modalities (6%). Seventy-one percent of all practices with Internet access used it for clinical purposes, for instance, to communicate with patients or to retrieve clinical information. Only 31% of respondents had Internet access from all chairside computers, and 12%

Table 5 ■ Opinions about Several Aspects of Chairside Computing, the Categorized Responses, and the Number of Mentions

Aspect of Chairside Computing	Categorized Responses	No. of Mentions*	%†
Practice management system features liked (n = 97)	Charting	35	36
	Treatment planning	27	28
	Imaging	21	22
	Scheduling	18	19
	Progress notes	9	9
Practice management system features disliked (n = 97)	None	25	26
	Usability	15	15
	Functionality	15	15
	Charting	12	12
	Inability to customize	6	6
Barriers (n = 95)	Insufficient operational reliability (such as crashes)	15	16
	Program limitations	13	14
	Learning curve	13	14
	Cost	12	13
	Infection control issues	11	12
Advantages (n = 96)	Efficiency	70	73
	Convenient information access	23	24
	Patient education	22	23
	Organization	18	19
	Imaging	17	18
Disadvantages (n = 95)	None	30	32
	Insufficient operational reliability (such as crashes)	18	19
	Cost	10	11
	Infection control issues	10	11
	Insufficient usability	9	9
Potential improvements (n = 94)	Better input methods	35	37
	Smaller computers	14	15
	Better user interface design	9	10
	Faster computers	7	7
	Improved digital radiology	7	7

Only the top five responses are listed in each category.
*Respondents could give multiple responses.
†Percentages are calculated the respective n.

Table 6 ■ Percentage of Respondents Using the Internet to Access Each Information Category with the Indicated Frequency (n = 55)

	Daily	Weekly	Monthly or Less	Never
Diagnosis	4	11	58	27
Treatment	5	15	56	24
Products	4	40	51	5
Medical conditions	5	11	68	16
Drugs	5	13	42	40
Patient education	7	9	60	24

from some. The reasons for equipping no or only some operatories with Internet access included no need, exclusively administrative use, security and privacy concerns, and the potential for personal use.

We asked respondents how often they accessed the Internet to retrieve various types of clinical information, for instance, about diagnoses, treatment, products, medical conditions, drugs, and patient education in a given time period. As Table 6 shows, very few respondents did so on a daily basis. The majority accessed such information weekly or monthly or less. Product information was the most frequently accessed information on the Internet.

Forty-three percent of the practices with Internet access (n = 99) used e-mail for clinical purposes, for instance, with patients and colleagues outside the office. E-mail use with colleagues was more frequent (56% of e-mail users communicated with them either daily or weekly) than with patients (36% of e-mail users communicated with them either daily or weekly).

When asked whether they considered the Internet essential to clinical practice in dentistry, 23% (n = 56) of respondents answered "very essential," 55% "somewhat essential," and 21% "not at all essential." (Total differs from 100 due to rounding.)

National Health Information Infrastructure

The NHII will significantly influence how care providers access and use clinical information and is now receiving increased attention also in dentistry.[20] We briefly introduced the NHII in the interview and asked respondents whether they would consider the NHII useful for dentistry. Of 84 respondents, 86% answered "yes," 11% "maybe," and 4% "no." (Total differs from 100 due to rounding.) The reasons cited for why the NHII was considered useful included efficiency in communicating with physicians about specific patients, convenience in sharing patient information, having more reliable information available (e.g., compared to the information provided by patients), and obtaining better information about the patient's medication history. When asked whether they would allow other providers to access information about their patients, 55% (n = 83) of the respondents answered "yes," 35% "maybe," and 10% "no." Many qualified their answer by indicating that they would require a certain level of control over who accessed what kind of information.

Discussion

Currently, 25% of all general dentists use a computer at chairside. This level of adoption is the result of a relatively recent trend; approximately 80% of our respondents began to use a computer at chairside within the past 10 years. Based on general experience with technology adoption, this trend should continue, and maybe even accelerate, in the coming years. Chairside computing is more likely to be adopted by group than solo practices. Group practices may be better able to cope with its high costs, which our study identified as a barrier to implementation. Many respondents routinely access patient information from their operatories, consultation rooms, and homes. Thus, they implement "ubiquitous access" to patient data envisioned for computer-based patient records[21] at least within their own environment.

Participants stored a significant amount of clinical information, but by far not all of it, on computers. Many practices duplicated a significant amount of clinical information on paper. In converting from paper- to computer-based systems, many practices seem to go through a more or less lengthy transition phase. There may be several reasons for this. In the interviews, many dentists indicated that they were not comfortable switching completely to computer-based storage for patient information until they were satisfied that the system was reliable. Second, many practices were implementing chairside computing in stages, and consequently had to maintain hybrid systems for some time. A third reason was that information on the computer is often not an exact representation of information on paper. For instance, handwriting and special notations on paper charts provide much more flexibility in recording information than do dental software applications.

Data entry was performed by the entire dental team, including dentists, hygienists, assistants, and front desk personnel. No clear division of labor was evident, as, for instance, in medical transcription using typists. As a rule, dental assistants and hygienists were the primary data entry personnel, as evidenced by the fact that they recorded data in 61% of all information categories across practices.

Respondents were clearly interested in methods that make interacting with a computer easier. In the operatory, the charting interface is one of the most frequently used parts of a PMS, but it is also one with an extremely complex visual and information design (Fig. 4). Touch screens and voice input are evidence that dentists would like to use alternatives to the traditional mouse/keyboard interaction paradigm. However, the large number of participants who tried and abandoned voice recognition shows that the technology may not be mature enough to be used on a routine basis. Continuous progress in developing speech recognition[22] may alleviate some of the problems common in the past.

Aside from human-computer interaction challenges, respondents identified several other problems with their practice management systems and chairside computing in general. General barriers for chairside computing identified include insufficient operational reliability, the learning curve, cost, and infection-control issues. Several respondents, especially those who relied heavily on the computer for clinical care, commented that they essentially can close their practice when the computer is "down." The steep learning curve is a consequence of the complexity of practice management applications, which typically support both administrative and clinical functions. While many dentists take advantage of vendor-provided training during system installation, they typically do not do so after the system is in routine operation. A steep learning curve therefore strains existing personnel resources when new employees are hired. Last, the problem of

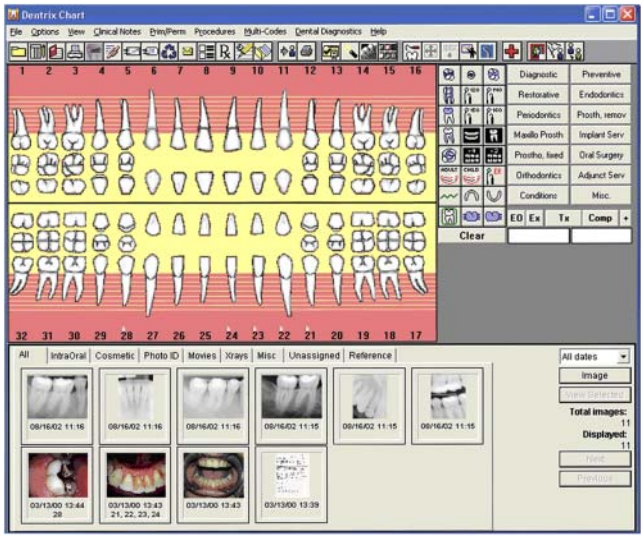

Figure 4. Charting interface of the Dentrix Digital Office application (image courtesy and copyright of Dentrix Dental Systems, American Fork, UT).

infection control highlights the fact that off-the-shelf mice, keyboards, and screens are less than appropriate for environments in which biological contamination is an issue.

While computers at chairside provide significant utility for the practices that we studied, the Internet seems to play a less important role. Almost all offices had Internet access, but only 40% used it in the operatory. With the exception of products, between 16% and 40% of respondents never accessed clinical information on the Internet. Over half of the respondents e-mailed colleagues outside the office either daily or weekly, while approximately one third did so with patients. At this time, the primary value of the Internet seems to be to enable communication within the professional community. These results are similar to those of an earlier study[23] that found that e-mailing colleagues was one of the primary mechanisms for solving patient-specific questions among users of an Internet discussion list.

Despite the fact that the NHII was a concept that few of our respondents had ever considered in the context of their practice, many respondents clearly articulated their opinions about its potential usefulness and limitations. Over 85% of the respondents regarded the NHII as potentially useful to their practice by facilitating communication with other health care providers, and easing access to relevant and valid patient information. Despite dentistry's insular practice profile (73% of all dentists are in solo practice), the dentists in our sample seemed to see themselves as part of the larger "health care team."

We believe that the results of our study are generalizable to the population of general dentists in the United States for three reasons. First, unlike other studies, we used a random sample drawn from all general dentists in the United States. Second, several of the quantitative and qualitative results of our survey are in line with previous findings.[6,10,23] Third, the respondents were statistically identical to nonrespondents with respect to age, gender, ethnicity, and geographic region. At the same time, the study is subject to several limitations. The cumulative response rate of 35.7% is comparatively low, even if allowing for the lack of attraction of a relatively lengthy telephone survey. Self-reported data are typically less reliable than those obtained through more stringent methods, such as direct observation. Answers to questions about past behavior can be affected by recall bias. The novelty and comprehensiveness of this survey may have generated less reliable answers than more common survey topics. Despite those limitations, we believe that this study has provided a relatively accurate snapshot of current chairside computing and Internet use in clinical dentistry.

Table 7 ■ Percentage of Respondents Using E-mail to Communicate with Patients and Colleagues Outside the Office (n = 43)

	Daily	Weekly	Monthly or Less	Never
Patients	16	20	41	23
Colleagues outside the office	14	42	35	9

Conclusion

The use of chairside computing in 25% of all general dental practices compares favorably with the corresponding proportion in medicine. Approximately 20% to 25% of physician offices use CPRs.[2] However, this study has shown that chairside computing in dentistry is not an all-or-nothing proposition. The vast majority of practices in our study continues to maintain paper-based storage while implementing electronic systems. On the other hand, the rapid movement toward adopting computers at chairside and the emergence of systems that serve clinical needs more comprehensively than previously bode well for issues such as the quality of documentation in health care, computer-based decision support, access to patient-specific information by the whole dental team as well as their external colleagues, the NHII, and public health and epidemiological databases.

To exploit those possibilities, future research should address a number of areas. First, early research has found that clinical decision support in dentistry could be potentially useful in such areas as dental emergencies and trauma, orofacial pain, oral medicine, oral radiology, orthodontics, pulpal diagnosis, and restorative dentistry.[25] To take advantage of these opportunities, we need to enable dentists to interact more directly with the computer during clinical care. Research on decision support systems has shown that effective systems work best when they deliver information to the decision maker at the time and place when it is needed and when they fit into the workflow.[24] Second, we need to develop easier and more efficient methods for data entry, which can produce a number of benefits. Office efficiency may be improved because the personnel generating the data can directly record them (instead of, for instance, dictating them to someone else). The quality of clinical documentation may increase because fewer keystrokes and mouseclicks typically translate to fewer errors. In addition, simpler and better designed systems can reduce the learning curve. A third question for future research is the representativeness and expressiveness of computer-based documentation compared to its paper-based counterpart. Computer-based systems must match or exceed paper in terms of what clinically relevant information is stored and how it is displayed.[26] These research questions should be addressed in the context of integration.[14] Integration will not only help support the user- and task-centered design of the clinical computing infrastructure, it will also

connect clinicians to external resources, such as the NHII and evidence-based information resources, which will be increasingly essential to delivering dental care in the future.

This article also has laid the groundwork for several other research questions that are not directly associated with clinical care and patient outcomes. Addressing some of these questions successfully may reap benefits in terms of improved operational efficiency, reduced cost, and enhanced capacity for patient care services. For instance, one issue to be addressed is the lengthy transition phase from paper- to computer-based systems. Shortening the time that hybrid systems must be maintained can save money and personnel effort. Second, reducing system and implementation costs can free up capital and resources that can be invested in other, value-added activities. Last, better workflow support can increase office efficiency.

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