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Edited by O. Rienhoff and D. A. B. Lindberg

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J.J. Salley J.L. Zimmerman
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Dental Informatics: Strategic Issues for the Dental Profession

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Fourth Row, Left to Right Lawrence Weed, Richard Adelson, Donald A.B. Lindberg, Mark Diehl, Anthony Kiser, Howard L. Bailit, Harold E. Donnell, Jr.

FOREWORD

During the course of this year, 1990, dentistry will celebrate its sesquicentennial as a profession. In February 1840, the Baltimore College of Dental Surgery, the Dental School of the University of Maryland, was chartered by the Maryland General Assembly as the world's first dental school. In the same year the American Society of Dental Surgeons, the antecedent of the present day American Dental Association, was founded, also in Baltimore. In the previous year, 1839, the American Journal of Dental Science was initiated as the first periodic scientific and professional publication in dentistry, later evolving to the Journal of the American Dental Association. With the congruence of three fundamental elements which are essential to any profession--a unique program of education, a formal means to communicate and freely share new information, and an organization devoted to maintenance of professional ethics and standards through self-regulation--dentistry began evolving to its current status as a valued and respected health profession.

From its birth and through the intervening century and a half, dentistry has been a profession heavily reliant on technology as well as science. Dentists variously are credited with the discovery and development of general anesthesia and the precision casting technique; and they make significant use of rotary cutting instruments, ultrasonics, laser technology, unique biomaterials, and intraosseous implants, to mention only a few techniques.

Interest by the dental profession in the advantages and assets accruing from the information age that has become so pervasive in the last two decades has likewise been strong, albeit not organized or coordinated. While the term "informatics" is a relative newcomer to the lexicon of dentistry, various electronically-based information technologies have been developed and used by dental professionals since the 1950s. Computer-assisted instruction, continuing dental education by television with satellite transmission, computer storage and analysis of research data, and practice management by electronic means are staples in dentistry's technology armamentarium today. At the end of this decade, it is estimated by the American Dental Association that more than three-quarters of dental practitioners in the U.S. will have microcomputers in their offices; and as new graduates replace retiring dentists, there will be additional cohorts of dental professionals each year that are at a minimum computer-literate and more likely computer experienced through extensive use of information technology from elementary education onward.

A major challenge facing dentistry in the 1990s to be met by all sectors of the profession will be preparing dental practitioners to deliver high quality oral health care in an environment undergoing change brought about by significant changes in patterns of dental disease, a shift in the demography of the patient clientele, and the exponential growth of new knowledge, the timely use of which can result in improved quality of care. Responding to this challenge will take the combined efforts of today's leaders in the major dental organizations (practice, education, research), plus the talent of a number of individuals in developing, testing, integrating, and applying a variety of information technologies. The diversity of organizations and individuals comprising dentistry and the pervasiveness of the informatics field, real and potential, suggest strongly that the first step in developing dental informatics is to bring the various sectors of the profession together to initiate strategic planning. Recognition of the need for planning evolved the need for this conference--a forum designed to accommodate exploration of the state of the art in dental informatics, presentations by colleagues from other health fields, and small group discussions focusing on teaching, research, and practice in dentistry, all leading to consensus concerning the directions the profession must take in order to achieve maximum advantage as it prepares for entering the twenty-first century.

ACKNOWLEDGMENTS

The editors wish to acknowledge the contributions of several individuals and groups in the planning for and implementation of this conference. First and foremost, we express deep gratitude to the Westinghouse Electronics Systems Group and Dr. John A. Decaire and Abol Ardalan of that organization for their active participation in the conference and for providing the financial support which made the conference possible. We view Westinghouse and its representatives as perceptive and generous corporate partners in this enterprise.

We extend special appreciation to Dr. Donald A.B. Lindberg, Director of the National Library of Medicine, for his help in setting the tone of the conference in his keynote address, and for his sensitivity to the needs of dentistry as dental informatics develops. Drs. Morris Collen, Marion Ball, Lawrence Weed, and Howard Bailit each presented information which, when read and reread, grows in substance and value. The workshop leaders, Drs. Louis Abbey, John Eisner, and James Lipton, captured with great accuracy the essence of the often far ranging discussions in each workshop group, and the coordinators of the conference, Drs. Gerald Gladstein and John Zimmerman, did an unusually fine job of maintaining momentum as well as synthesizing the overall content of the conference. And, we extend our thanks to the staff of the Aspen Institute Wye Conference Center for the unique ambience the Center provides, and for their continuing assistance and attention to our needs during the conference.

Dr. Richard Mumma, Jr. and Carolyn Gray of the American Association of Dental Schools were instrumental in the planning of the conference; sincere appreciation must be expressed to them and to several staff of the University of Maryland at Baltimore. Sandra Rogers, Joann Sommers, David Rupkey, and Frank Hodges made important contributions before, during and after the conference, which ensured its success.

Finally, a conference of this nature and format will produce results that are a direct function of the interest and participation of each person in attendance. We were especially fortunate to have a group of individuals who brought a wide and varied range of backgrounds and experiences to the table, but who all had in common perspectives which were knowledgeable, well founded, and freely expressed.

To all mentioned above must go full credit for the impact this conference has already had and the hoped-for influence it should have on dental informatics as it develops into a unique field of endeavor, serving dental professionals and the public for whom they provide oral health care.

The Editors:

John J. Salley
John L. Zimmerman
Marion J. Ball

Baltimore, Maryland
February 1990

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Appendixes

Part 1-Dental Informatics: What, Why, Who, Where, and When

> Health informatics is defined as a new knowledge domain of computer and information science, engineering and technology in all fields of health and medicine, including research, education and practice.
>
> Morris Collen, M.D.
> 1986

Since the close of World War II, electronic information systems have had major impact on almost all segments of human endeavor. Over the last two decades computing equipment has increased in power and decreased in size and cost so that computers are now readily available to individuals and corporate bodies alike. They have become indispensable in business, finance, commerce, manufacturing, transportation, national defense, government, education, and so on. The health care field is heavily reliant on electronic information systems in all sectors as well, with greatest use in the corporate entities: hospitals, clinics, health-related industries, third-party reimbursement organizations, and the like.

More recently, the development of micro and personal computers has created a powerful adjunct to management of diverse activities ranging from household management by a homemaker to managing individual dental and medical practices. While miniaturization of computer hardware has brought on the "information age," the vast array of computer applications would not be possible without parallel development of requisite software enabling personal computers to perform the broad array of tasks of which they are capable.

Low cost, reliable personal computers and off-the-shelf software are now readily available to physicians, dentists, pharmacists, and other health professionals using electronic data systems in their individual practices. However, the applications utilized most commonly are in financial management with some use in recording and storage of patient clinical data. The next promise of electronic information systems application in the health field may be the development of artificial intelligence and expert systems to assist health care practitioners in making better and more informed clinical decisions. This can be done through mobilizing the knowledge and expertise of leading clinicians and clinical research scientists in academic health centers, integrating this information into a series of expert systems, and making this knowledge base readily available to practitioners. Expert systems can then be integrated with patient care activities of individual clinicians through networking, and can be easily updated in the university setting. Therefore, the time between discovery in university laboratories and clinics and reduction to practice in the community can be reduced significantly to the benefit of individual patients and society.

What Is Informatics?

Although the term "informatics" has become familiar among a relatively small group of specialists in computing, a universal definition is still not recognized in the academic arena. Informatics combines the fields of computer science and information science and applies this new approach and body of knowledge to solving problems of information collection, management, and distribution. The emphasis in the field of informatics is on computers and information technology as tools and not as an end unto themselves. The singular study of computer science or of information science without application is not informatics.

In the context of this conference on dental informatics and throughout this report, the term "medical informatics" is used generically to embrace all healthcare professions. At this early stage of development, however, an association with a specific healthcare profession, i.e., dentistry, helps to build a strong group of constituents and lends to easy identification within that group of professionals. While the term "dental" has been used with informatics to denote the developing body of knowledge that focuses on the organization and management of information in support of dentistry, Collen's definition of health informatics above is very well stated and inclusive of all of the professions devoted to health care.

Why DENTAL Informatics?

As the end of the twentieth century approaches, it is evident that dentistry is undergoing very significant changes which will influence its systems of education and delivery of care for many years to come. In essence the universe of diseases for which dentists assume direct responsibility is expanding beyond dental caries, periodontal disease, and malocclusion. Dental practitioners see a wide variety of other diseases also---some systemic in scope but with important and vital oral manifestations requiring dental intervention; others requiring in-depth knowledge of clinical pharmacology; still others, i.e., HIV infections, where oral pathology may be the first sign of an otherwise latent disease process.

Two changes in dentistry are noteworthy insofar as informatics is concerned. For the last decade or so the dental profession has seen and documented altered patterns of dental disease. A slow but progressive decline in dental caries is most responsible for the changing patterns of disease, and clearly is an effect of communal water fluoridation, but is influenced also by a more affluent, better educated public that practices improved oral hygiene. The other change of note impacts on the delivery system directly and is demographic in nature. In contrast to 20 years ago, dentists are seeing growing numbers of persons who are 65 years and older, many of whom are taking a variety of medications. They are also being called upon to see patients who are physically or mentally handicapped or otherwise medically compromised, requiring more frequent interaction with other health professionals.

These two factors alone, altered patterns of an important disease and changing demography of the patient clientele, are leading to new and greater emphasis in dentistry on oral diagnosis and oral medicine with potentially less emphasis on the biomechanical aspects of dental care. An important result is the need for dentists to manage a much larger body of knowledge with more frequency than in the past; and this body of knowledge of necessity will include a huge base of factual information, the daily utilization of which can assist dental practitioners in meeting new challenges in patient management. It is important to recognize, therefore, that all of dentistry, practitioners, educators, and others, is experiencing a need to improve the organization, storage, retrieval, and utilization of ever growing amounts of factual data. This can only be done effectively by application of modern information technologies.

Dentistry and electronically based information technology are not new to each other. As early as 1950, dental educators pioneered the use of closed circuit television and its facility for image amplification through electronics technology. Dental continuing education courses were first distributed by video telecommunications via satellite transmission in the 1960s; and in anticipation of the growth of reimbursement for health care services by third party payors, the American Dental Association (ADA) in 1969 developed a standardized dental disease coding system which introduced automation and computer processing of claims for reimbursement for dental treatment. This ADA-sanctioned system of disease codes has never been seriously challenged and thus enjoys universal use today by practitioners, demographers, insurance companies, and government agencies.

There are two approaches to dental informatics within each of three functional groups, namely, education, practice, and research. For example, a practitioner can do research and development in new applications of technology and information science as applied to dental practice; or a practitioner can use existing technology and information science techniques during the delivery of dental care. The former is an example of the more traditional research method, while the latter is the application of informatics tools and knowledge. Both of these areas are felt to be important, and this conference as it was first conceptualized addressed dental informatics with this broad approach. In addition, informatics also addresses educational and training objectives and methods that are required to bring this new body of knowledge to predoctoral students as well as professionals already in the field.

The Driving Forces That Initiated This Conference

There have been several isolated attempts to bring computer technologies to the dental practitioner. The American Dental Association and several state dental associations have developed and marketed a computerized dental office management system, and the ADA also attempted to start a nation-wide electronic communication network for dentists. Individuals in schools of dentistry, the Federal dental services and private industry have developed electronic dental record systems, expert systems, and information systems, and have started to address data format and communication standards; but these activities have grown up in relative isolation from one another. It was not until 1987, when the American Association of Dental Schools formed a special committee on information technology, that dental informatics was addressed from a national perspective with interests on the behalf of the entire dental profession.

During this same time period the National Library of Medicine implemented an extramural program called IAIMS, Integrated Academic Information Management Systems. This program emphasizes the importance of planning for information management and the need to integrate diverse and distant information sources into a single access point for the user. Various dental organizations, in particular the AADS, began to look to this program for direction in the planning of dental informatics. The University of Maryland at Baltimore was active in the IAIMS initiative and had been awarded a planning grant and then a pilot grant by the National Library of Medicine. The liaison that developed at the UMAB campus between the computer center, the Information Resources Management Division, and the dental school produced the first Division of Dental Informatics within a dental school, and an interest by individuals within IRMD to further the development of dental informatics.

In a matter of only a few months, those involved in the three separate initiatives just described began to coalesce their efforts through the commonly held belief that all segments in dentistry would benefit if dental practitioners, educators, and researchers pooled their energies to work toward a coordinated strategic plan for dental informatics. With staff support from the AADS and UMAB, an ad hoc working group comprised of dentists and advocates for informatics was formed to plan for a meeting that would bring together the major forces in dentistry to outline a plan for the future of dental informatics. Funding for this conference was generously provided by the Westinghouse Electronics Systems Group. Westinghouse officials recognized the potential of the vast dental market for informatics products and services. The Corporation's long and distinguished history in developing and manufacturing state-of-the-art electronic equipment and information systems prepared them exceptionally well for this new venture. Dentistry represents but one of many healthcare markets that are open to high tech companies looking to diversify.

Conference Participants

For this first planning conference to be truly effective, the participants in attendance had to represent all aspects of the dental profession. One group of attendees thus represented the major organizations in dentistry and were able to speak for the organizations concerning their goals, objectives, and long range interests. This group of attendees was selected on the basis of their policy and organizational strengths, interest, and affiliations. A second group of participants was selected for their knowledge and expertise in informatics. The combined knowledge in the form of the organizational strengths brought by the representatives from professional dental organizations and the specialized knowledge of the technical attendees produced a diverse group that was capable of addressing the organizational issues within a highly technical context. The complete listing of conference participants and represented organizations is included in the appendix.

Also in attendance was a group of recognized informatics experts from other health fields who presented the topical papers in Part 2. These informatics experts provided formalized information in the form of speeches, demonstrations, and papers, as well as direct knowledge imparted during the group discussions. Without the combined knowledge and experience of Drs. Lindberg, Collen, Ball, Bailet, and

Weed, this conference would not have reached the level of outcome that it did.

Conference Goals

The following list of conference goals was formulated prior to the meeting at the Aspen Institute and was distributed to each participant before arriving at the Wye Conference Center.

- Define the parameters of dental informatics across all levels of dental organizations and activities.
- Develop strategies that will foster optimal use of dental informatics resources.
- Identify specific areas for research and development in dental informatics where the various segments of the dental profession could concentrate their efforts.
- Identify areas for cooperative ventures and projects between professional organizations, educational institutions, government, and industry.
- Lay the foundation for a cooperative strategic plan for dental informatics for the entire dental profession, so that individual components in dentistry can coordinate and accommodate their informatics planning and activities with the overall plan for dentistry.

Part 2-Contributed Papers

1- Keynote Address: Informatics in Dentistry

Donald A. B. Lindberg

I want to begin by extending congratulations to this group for assembling with the purpose of planning to improve dentistry and dental health care through expanded use of informatics. I think this is a wonderful enterprise, and I think you have done extremely well thus far. The National Library of Medicine (NLM) collects books and journals extensively from the field of dentistry; I hope that we serve the dental profession well, and I hope we will serve it even better with your help. I will give you more detail on coverage and usage later in this presentation. First, I would like to mention several NLM programs that are open to dental professionals:

There is a program of research grants, peer reviewed as they are at other NIH Institutes, in which the dental professions may participate. We never have enough funding to meet the need but we welcome the opportunity to review your proposals.

Second, there is a medical informatics Training Program, now at eight sites in the country. NLM has the only authority for medical informatics training in the government and has done this for about 20 years. I ran a training grant program at the University of Missouri School of Medicine for 14 years where we always sought dental participation. Some training programs did this; some did not. There is full authority to include dentists in those programs, and I am sorry we do not have more.

A third program of special note is IAIMS, Integrated Academic Information Management Systems. It sounds very bureaucratic, but I assure you that the bureaucrats did not dream it up. The Association of American Medical Colleges conceived it, and NLM implemented it. It is an initiative to support schools that want to develop a school-wide plan for information services, where school-wide means including all the relevant health professions, relevant sites, and relevant modalities. It is not a question of inventing things; rather it is a question of using what already exists in integrated fashion for the benefit of all health science departments on a campus. As it turns out, the schools spend far more money in the process than the government, but since it is for the benefit of the schools this is probably a fair enough division of resources. The University of Maryland is one of the leaders in IAIMS, and there are others as well.

There are new outreach programs at NLM that definitely embrace dentistry, at least to the extent that they will help us understand needs as well as help us implement some expanded outreach to dental professionals. I will talk more about these later.

NLM and the National Institute of Dental Research (NIDR) have a happy and collegial relationship; its director, Dr. Harold Loe, is extremely well respected on our campus, as I am sure he is on yours. NIDR was the third Institute created at NIH, so it has a long and productive history. At the time I joined NLM in 1984, I knew it quite well because anyone who does health research on computers learns about NLM quickly. It was a pleasant surprise to find out how impressive was the rest of NIH. One of the happy surprises was to discover again and again the extremely high quality of research done at NIDR. If you surveyed the important projects at NIH, a significant number would turn out to be in or sponsored by NIDR. NIDR exemplifies basic research, and we are grateful to have a good relationship with them--another example of the tenet that the institutes at NIH do not compete with one another; they help each other.

I now want to address the plan that you are working on. Recently, I re-read the presentation that was made to the Board of Regents at NLM in November 1988 by several representatives of the dental profession, and I must say it bears up today quite well; it makes a lot of sense. This conference is an introduction, a formal beginning, in your planning process. You may want to consider the actual process of planning as a method for predicting the future. One way is to look at trends; futurologists often do planning on the basis of trend projection. Another approach is the incremental method. I think that is what you are doing. You are saying, here are all of the aspects of the informatics field; here are all of the activities; these are the good ones; and we wish to expand upon them. Clearly, this is a sensible and well proved method with which to construct a plan.

Another alternative method is one we used with success at NLM in 1985-86. I would call this third method of planning "prospective-analytic." We assembled advisors in small groups. The period we planned for was 20 years--1985 to 2005. We asked such questions as: What will the world be like 20 years from now? What role do we want NLM to play in it? What are the obstacles for us? What are the windows of opportunity?

There is no magic in this method; I simply bring it to your attention as an alternative paradigm.

The only other comment I want to make about planning methodology has to do with the way you express yourselves. I would say the goals are properly stated at this point; they are rather broad, but in the end, you want to be careful as you bring your results to the attention of the dental profession and the larger public. To the latter audience it is very important to express your informatics program in public policy terms that are simple to understand and meaningful to the individual. The individual citizen basically is unconcerned about what problems dentists (or physicians or lawyers) have. That is what they pay you for. You do not tell people to brush their teeth because it will help the dentist or increase the gross national product. You say it will help them each as individuals. The plan has to be in terms lay people can understand. Dentists aim to improve oral health care; how is information technology going to improve care for the individual citizen? This is what the public believes is important.

Clearly, your agenda for this conference contains a long list of things to do in order to organize and to expand informatics in dentistry, but you have to have priorities. For example, are you speaking about the desire for a problem-solving curriculum in the dental schools? Is that more important than continuing dental education? How does the need for clinical record-keeping systems relate to development of a reference data base? We speak of establishing new standards, but does this need compete with the need to keep up with those currently available? Research versus outreach--these are two different activities: what is the relative importance of each? Training in medical informatics--is it for students, for faculty, for practitioners? Who comes first? I will say that your approach does capture the attention of students, probably a whole lot better than turning out the lights and projecting slides. But, is it an optimal way to understand dentistry?

It is a given in any planning exercise that priorities be developed, and in this instance you and your colleagues must bear that responsibility. To me, the number one priority, clearly head and shoulders above everything else, is to discover who needs and uses information amongst the dental professionals in their work, to what end and with what benefit. In medical informatics, I operate with a definition that is even simpler than the one provided to you in the conference materials. Medical informatics is the attempt to establish a theoretical basis for the use of automated information systems in health care. But, since information is the key element, we want to know who uses the information for what purpose, what is the outcome, and who benefits. I might add that these are questions the Congress often asks.

Another priority reasonably high on the list should be access to the scientific literature. This is an obvious bias of someone from NLM, so it will be no surprise to you that I want to talk about it. If it turns out to be significant on your list of priorities, then we need to discuss MEDLINE and the other MEDLARS databases. This is compatible with the idea of "building to existing strengths." If you stop and think about it, if there were no NLM, if there were no MEDLINE, there would probably be no indexing, collecting, and ordering of the dental literature. Even so, maximum advantage is not being taken of the present systems.

I would like to turn now to potential projects that could relate directly to current NLM programs. First, some background. NLM is the largest biomedical library in the world, including dentistry. There is an extensive interlibrary loan operation in which dentistry participates strongly. The borrowing frequency of the top journals in dentistry in the national interlibrary loan system is easily seen through a widely used computerized document delivery system run by NLM. In contrast, the online use by dentists of the computerized reference database is weak. I regret to say that dentistry has left itself plenty of room for improvement. NLM's computers are queried for references four million times a year, 24 hours a day; of those, only one-half of one percent are for dental clients. Clearly dental use of online information systems is way under what it should be. MEDLINE includes references from 403 dental journals, or about 11 percent of all journals indexed, which to me is pretty ample coverage. Paradoxically, 2.6 percent of all citations retrieved come from those journals. Remembering that use by dentists makes up one-half of one percent, one must conclude that other people make more use of dental literature than do dentists.

Concerning other dental use data, we are pleased that there are 61 dental schools affiliated with NLM. Of these, 35 use Grateful MED as their method of access. On the other hand, of the 140,000 practicing dentists, does anyone want to guess how many have an account at NLM? Only 76. Here, too, there is great room for improvement. Some may get literature search services through academic health centers or professional societies, but the ratio between the schools and individual use is about 10 or 12 to 1. This means that the active research and teaching faculty constitutes the bulk of users and the individual practitioners have not caught up yet.

Another important issue is to determine when and how NLM services are used. The small numbers are an advantage in this. Questions more easily examined are: What are the online systems used for? What are the outcomes? What are the benefits? Presently we are engaged in a study using the critical incident technique (CIT) to learn more about our four million searches a year. I had asked my staff who the users are and what are they doing, and no one knew! Limited information about interactions can be retrieved from our mainframe computer logs. But what are the users actually doing? If a user did a search, received an answer and then quit, can I assume that user was satisfied, or might the search have been a "bummer" and might the user have gone to the Merck Manual? This is a difficult analysis to do, but we are now going through about 1400 selected searches in scientific fashion using personal interviews with individual users. The initial yield is extremely interesting and should be very helpful to NLM. With your help and interest, we could do a CIT study of our dentist users. We want to know if we are not doing a good job. If the users are trapped in a situation where the right indexing terms are not used or the coverage is not adequate, we need to know this.

Grateful MED is a user-friendly, front-end program for IBM or Macintosh personal computers, or compatible machines. Grateful MED is meant to serve the individual health care practitioner, the end user. I certainly hope it is adequate for dentistry. However, if a specialized version is needed, it can be easily accomplished. I invite your help in understanding the requirements. Grateful MED is inexpensive at $29.95, and we have eliminated any minimum charge for having NLM account. Half-price discounts are available to students, including dental students.

If the scientific literature is to be of maximum benefit to practice, a much larger number of health professionals must be served. The scientific literature is what separates modern medicine and dentistry from the Middle Ages. It is the basis of our professions and gives them validity. Essentially what we are doing on outreach is turning on the power switch and saying let it boot up the system for you. In my opinion, Grateful MED is a very good start for a dentist or physician in personal computing, because meaningful questions are asked and the practitioner can evaluate the responses on an individual basis.

Another category in the same vein includes special new files and improvement of existing ones. A program called DentalProj is a database on dental research projects created by the NIDR to run on the NLM online network. It is similar to the cancer protocol plan where the subject matter expertise resides in the National Cancer Institute at NIH, with NLM serving to disseminate and distribute the information.

Currently, DentalProj has about 1300 NIH-funded, dental-related research projects plus others that are voluntarily contributed. As DentalProj is built, it should be capable of including expired projects as well and should have a back file.

How good is MEDLINE itself in dental coverage? How good is the indexing? To find out, we need your help. We evaluate MEDLINE on a daily basis. Its controlled vocabulary--Medical Subject Headings--used for indexing the literature, has been successful because it is critiqued and updated frequently. This is another area where dentists collaborate with NLM.

With respect to training, we need more slots in existing training grant sites as dental informatics develops. Positions could be earmarked for dentists. We need more positions, but we also need more applicants and more money to pay for them. There are additional potential sites in other universities for future training programs. We managed to double the number of trainees in 1986, and hope to repeat this in the not too distant future. In addition to supporting training programs, we have introduced individual fellowships in medical informatics.

I want to mention the Unified Medical Language System (UMLS) because this is another possible way for you to make joint cause with NLM. The goal of UMLS is to bridge the gap between the language as it is used in clinical medicine and clinical dentistry and the more formal language that is used to index the literature, to make reimbursement payments, and so forth. The UMLS is designed to do this automatically and not to restrict users to a limited vocabulary or numerical codes. We know that old-fashioned numerical coding systems cannot work on a broad scale. Rather, we want a system that is smart enough to understand what is meant when a clinician says something unambiguous in medical terms that can be translated to the fixed terminology that is used for formal purposes. Currently, UMLS does not have a dental component; however, it certainly could and it should. If you help us, it will.

At NLM, there is an outreach activity which is at the very top of my current list of priorities. A distinguished panel which included Dr. Ball and Dr. Salley and was chaired by Dr. Michael DeBakey has told us at NLM to do more to make sure that individual health care practitioners as well as biomedical scientists use the computer systems and information systems we provide. The panel acknowledged that the Regional Medical Library Program has been a wonderful achievement from 1965 onward, but essentially it has dealt with institutions, and now it must focus more effort and resources on the individual physician, dentist, pharmacist, etc. In 1965 it would have been folly to believe that an individual physician or dentist would have his own computer, but now personal computers that sit on a desk have more power than early IBM mainframes.

I want to mention also one last possible source of mutual interest; it is the NLM advisory panel now dealing with long-range issues concerning digital medical images. We have not really concluded how far to go with it. The panel thinks in terms of a "visible man and woman" system--computer slices that would include the modalities nuclear magnetic resonance, computerized axial tomography, and histological slices. Such things are possible and are being done but only in isolated parts of the body. They need to be brought together into a whole organism.

The expert panel on imaging is tremendously impressed by the speed with which this new technique entered clinical practice. It is almost passing by first-and second-year students and the anatomists right out into the hands of the orthopedic surgeons and the neurosurgeons. Significant to this group are those who do oral and maxillo facial surgery and head-neck surgery, because they work in a very complicated part of the human anatomy. Already the state of the art is such that one can model the individual patient (not just an abstracted normal) and can create computer-generated tapes that drive lathes which make replacement parts for that individual. In patients with trauma or gunshot wounds, the system can make a mirror image of the remaining tissues in order to make a prosthetic implant. Clearly, this is another area where we might make common cause through extending this technology into such dental areas as orthodontics, prosthodontics, and restorative dentistry.

This ends my list of areas in informatics which are of common interest to NLM and dentistry. To summarize very briefly: I think that it is great that dentistry is moving forward in this area; there is an appropriate mix of people in this room; you are taking the appropriate steps. Remember, that selection of the problem is about 70 percent of the battle in an initiative of this kind. Choose your projects and be patient; a year or two is not going to see this through. Build through existing strengths and choose an approach so that whatever you do, you are ahead. Certain things will not work; there may not be enough money to do everything, but whatever you do, move toward goals which are selected so that 100 percent of the work need not be completed before there is a benefit. Be absolutely certain that the problem you tackle is major, meaningful, and understandable to society.

Given these caveats, I think the talent gathered here, plus the new people that you need to recruit, will shape and adapt informatics for dentistry so that it will become an essential tool in the dental armamentarium now and into the twenty-first century.

Thank you for your patience; I wish you the best of luck.

2- The History of Medical Informatics: Implications for Dental Informatics

Morris F. Collen

What Is Medical Informatics?

Medical informatics is a relatively new knowledge domain of computer and information science and technology, and computer-based communications in all fields of health and medicine, including research, education, and practice. As we shall see, it is so new that it did not receive its name until 1974, just 15 years ago.

Medical informatics has evolved over four decades as health professionals learned to exploit the extraordinary capabilities of the electronic digital computer in order to better meet their complex information needs.

Now, in the 1980s, automobiles and telephones are among the day-to-day tools of health professionals; yet computers are not. Paul Starr, in 1982, credited the telephone and the automobile with the greatest improvements in the productivity of the medical practitioner. According to Starr, physicians were among the first to use telephone exchanges which were built in the late 1870s to connect physicians with local drugstores and to communicate with patients requesting house calls. Henry Ford put out his first Model T automobile in 1908; and a Chicago dentist is said to have purchased the first Model A Ford on the market in 1927.

Although punched cards were being developed for the 1880 census at the time Alexander Bell was beginning to market the telephone, it is quite evident that physicians have been much slower to adopt the computer than either the telephone or the automobile. It has been estimated that there were about 250 computers in use in 1955, 15,000 in 1975, and millions in 1985. In 1988, a "Market Directory of Computers in Healthcare" listed 750 vendors of medical computer systems, applications, and supplies.

It is of interest to note that the automobile, which provided personal automated transportation and was first shown in the United States in 1900, ten years later was reported by the *Journal of the American Medical Association* as being generally adopted by the medical profession as its mode of travel. If history repeats itself, the introduction of the PC in 1981 should result in the personal computer being generally adopted by the medical profession as standard office equipment by 1991.

When devices carry out addition, subtraction, multiplication, and division, or the logical functions of "and," "or," and "not," then they are called "computers." The earliest references to any applications of electronic digital computers to medicine appeared in the 1950s in biophysics, bioengineering, and biomedical electronics publications. A variety of names for this new field appeared such as medical computing, medical computer science, computer medicine, medical EDP (electronic data processing), medical ADP (automatic data processing), medical information processing, medical information science, medical software engineering, and medical computer technology. These terms were often used interchangeably, for example, information science and computer science, as if what was processed (i.e., information) was the same as how it was processed (i.e., by computer). Yet it was not until the early 1970s that it became clearly evident there was a need to settle on a name for this new domain of medical knowledge. To agree upon "medical" was not very controversial, although some health professionals prefer the term "health" to "medical," and consider health professionals to include physicians, dentists, nurses, pharmacists, psychologists, etc.

To find a single term to include computers and information science, engineering, and technology was more difficult. Harrison wrote in 1984 in an article in *Science:* "It is the combined body of knowledge derived from the processes of investigation that are science, engineering, and technological innovation that has become a resource of unprecedented value.... There is no term in the English language to encompass this conglomerate of knowledge." Yet in the 1970s, the word "informatics" had begun to be used by some for this purpose. As early as 1976, the *Oxford English Dictionary* defined "informatics" as the "study of information processing and computer science"; and credited the origin of the English word "informatics" to a translation from the Russian "informatika."

A search through the National Library of Medicine's MEDLARS CITE book catalog found that the combined English words "medical informatics" first appeared in 1974 in the International Federation for Information Processing,(IFIP) Medical Informatics Monograph Series, Volume I, entitled *Education in Informatics of Health Personnel.* The editors of this book, Anderson of London and Pages and Gremy of Paris, wanted the French word "informatique" to appear in the final name since that term was used in France for information science, and also implied "automatique" or data processing; so they were the first to incorporate the two English words to form the name "medical informatics."

During the 1960s, the French literature already had used the term "informatique medicale"; and departments with these titles had been established in the 1960s in France, Holland, and Belgium.

The term "medical informatics" became internationally accepted as a result of its use by the triennial International Congress for Medical Informatics, called MEDINFO. The first World Conference on Medical Informatics, MEDINFO 74, was held in Stockholm in August 1974. The last MEDINFO in 1986 was held in Washington, D.C.

In the 1980s, some health practitioners began to use the terms "dental informatics" and "nursing informatics," in addition to medical and health informatics.

A Brief Historical Review of Medical Informatics

From a historical viewpoint, the diffusion in the United States of new medical informatics technology over the past four decades resulted primarily from: (1) technology development; (2) governmental support and new legislation; and (3) professional and organizational support.

The Origins of Informatics Technology

The concept of the electronic digital computer has been attributed to a physician, John Shaw Billings, who became the first Director of the National Library of Medicine. Billings, while Assistant Surgeon General of the U.S. Army, was asked to assist the Census Bureau and take charge of the vital statistics for both the 1880 and 1890 censuses. Herman Hollerith, an engineer, went to work for the U.S. Census Bureau in 1879, the year that Billings started the *Index Medicus.* The census was handwritten onto cards that were then manually sorted into various categories and hand counted. To then obtain additional information required manual resorting and recounting. Billings asked Hollerith to work out a solution to this problem using punched cards. This resulted in Hollerith, inventing, in 1881, the punch card; he also built machines for electronically punching and sorting these cards. Billings was a member of the census committee which decided to use the Hollerith punch card system for tabulating the 1890 census. Hollerith went on to set up the Tabulating Machine Company which Thomas Watson, Sr. joined in 1914, and the company became the International Business Machines (IBM) Corporation in 1924. Credit for the invention of the first all-electronic digital computer has been generally given to the mathematician Alan M. Turing and his colleagues in England. It was called the Colossus and was operational by 1943.

Invention of the next electronic computer was generally credited to John Mauchly and his co-workers at the University of Pennsylvania, who patented in 1946 the ENIAC (Electronic Numerical Integrator and Calculator). ENIAC filled a 30-by 50-foot room, weighed 30 tons, used 18,000 vacuum tubes as its active logic elements, and had wired program plug boards and programming switches for storage. However, a court case between Honeywell and Sperry Rand in 1973 involving patent rights for computers concluded that Mauchly's group "did not themselves first invent the automatic electronic digital computer, but instead derived that subject matter from one Dr. John Vincent Atanasoff." Atanasoff, between 1937 and 1942, while a physics professor at Iowa State University, designed and built two electronic computers which used vacuum tubes to carry out computer operations and digital arithmetic. So, according to the courts, Atanasoff, an American, preceded Turing and was the first to invent an electronic digital computer.

In 1958, the second generation digital computers employed transistors instead of vacuum tubes and added magnetic core memory designed at the Massachusetts Institute of Technology by Jay Forrester and by Ken Olsen, who later became the founder and President of Digital Equipment Corporation (DEC).

In 1963, the third generation computers appeared in the form of solid state integrated circuits consisting of hundreds of transistors, diodes, and resistors embedded in tiny silicon chips, a process called large scale integration. This permitted the construction of a hierarchy of computers of different sizes. The IBM 360 series introduced in 1964 was one of the earliest third generation large mainframe computers. Minicomputers, smaller in size and designed to perform generalized though more limited tasks, were successfully marketed in the 1960s, especially by DEC as their Programmed Data Processor (PDP) series.

The first personal computers were built in 1971 by Blackenbaker (called Kenbak I), and by Hoff of Intel Corporation. Wazniak's Apple I appeared on the market in 1976 and Apple II in 1977; 130,000 Apple IIs had been sold by 1980. The IBM-PC was introduced in 1981 and was rated in 1988 by *Consumer Reports* as "the most successful personal computer design of all time." Since then, some 15 million models of essentially the same design have been sold in this country alone. The entry of the IBM PC began to accelerate the introduction of computers into medical offices, initially to facilitate office work tasks.

Also in the 1980s, the fourth generation of computers exploited very large scale integration (VLSI) containing thousands of components on very tiny silicon chips. They greatly increased performance despite their smaller size and lower cost. In hospitals and medical groups, personal computers as powerful as minicomputers began to replace large computers for some medical applications.

Although computer hardware has been the basis for most advances in informatics, it is the computer software, the computer languages and programs, which makes the hardware usable. A language and its software can readily modify the character of a computer. Just as there evolved different generations of computers, so there were developed different generations, or levels, of programming languages. Currently, it is evident that software is lagging behind hardware in satisfying the needs of medical informatics.

Communications are the means for transmitting information from one place to another. To allow communications between computers and to gather data from multiple computer sites, it was necessary to develop computer to communication interfaces, and build both local-area and wide-area networking systems. A local area network (LAN) connects on-site computers and peripheral devices, integrates departmental computing facilities, and usually connects to a supporting computer center. In 1971, Blois at the University of California, San Francisco, first proposed a prototype local-area network of distributed minicomputers in a hospital environment.

A major contribution to medical informatics occurred when the National Library of Medicine began the computerization of the *Index Medicus* with the printing of the 1964 edition, and implemented the computer-based Medical Literature Analysis and Retrieval System (MEDLARS). An online version of MEDLARS, MEDLINE, was initiated in 1971 with files dating back to 1966.

The Diffusion of Medical Information Systems

A medical information system (MIS) generally consists of several subsystems or modules such as an administrative information system, a clinical information system, and a clinical support system. In turn, an administrative or management information system includes ancillary systems for accounting and business functions, patient registration, scheduling, admission, discharge, and other patient processing activities. The term "clinical information system" is used for those components of a medical information system which are related to the clinical or direct care of patients. A clinical information system can comprise a hospital information system and an office information system, both with an associated computer-stored medical record. A hospital information system or an office information system, in turn, can each contain several modules or subsystem components called clinical departmental systems or clinical specialty systems, such as a cardiology system, pediatric system, oral surgery system, etc. Clinical support systems process patients' specimens, pictures, electrical signals, medications, etc., for which are included a clinical laboratory system, a pathology system, electrocardiography system, radiology system, pharmacy system, etc., which provide these essential support services to clinicians in the hospital and in the office. Affiliated care facilities might include systems for rehabilitation or nursing home care.

Through the years there evolved a set of goals for a medical information system to use computers and communications equipment to collect, store, process, retrieve, and communicate relevant patient care and administrative information for all activities and functions within the hospital, its outpatient medical offices, its clinical support services, and in addition any affiliated medical facilities. Such an integrated medical information system would have the capability of communicating and integrating into a computer-stored database all patient data during an individual patient's lifetime of care for services from all of the subsystems in the medical system complex; and also would provide administrative and clinical decision support.

Thus every MIS first had to develop very detailed specifications as to its functionality, the functional requirements of the system; that is, what did the ultimate users of the MIS want it to do for them? Then, giving these functional requirements to computer scientists and engineers would permit them to develop a set of technical specifications for the system; that is, the computer and communications designs and plans for the system to satisfy the users' functional requirements. Finally, the system could be purchased or developed, and installed in accordance with its technical specifications.

Every medical information system, whether processing data from inpatients or outpatients, had to: (1) identify and register the patient; (2) record time of the patient visit or transaction; (3) collect and store the patient data; (4) process and integrate the data into a computer-stored patient record which would be usable by health care professionals; (5) support the decision-making processes involved ln patient care; and

(6) communicate and provide capabilities for data linkages to other medical sites for transfer of patient care data. These functions varied in the hospital environment and in the medical offices in accordance with the logistics of data collection, and with the scope, volume, and rate of data captured. In physicians' offices, data from the patients were collected in the offices; patients were ambulatory and often well enough to use selfadministered questionnaires to enter their own medical histories. These outpatients then went to laboratories and radiology services, and their reports were sent to the physicians' offices to be filed in the patients' office records. Hospitals had sicker patients who were usually confined to bed rest, so data and laboratory specimens from the patients were collected mostly at the bedside. Inpatients' medical records were kept in the hospital; and sicker inpatients required larger amounts of data to be processed faster, so the hospitals' more severe functional requirements called for faster computers with more data storage capacity.

With the introduction of computers into medicine in the 1950s, it became evident that the computer could enhance the physicians' capabilities in all phases of medical practice; and physicians began to speculate about computer-based medical information systems. Occasional reports of projects involving the development of some components of medical information systems began to appear in the late 1950s. However, even with second generation computers employing transistors, computers were still large, slow, and expensive. They were linked to punch card readers and they transferred data between computers by magnetic tape.

By the mid-1960s, the introduction of solid state integrated circuits in third generation main frame computers, the use of lower cost minicomputers for special purpose applications, and improved operating systems and programming languages began to satisfy some of the technical requirements for medical information systems. A 1965 survey of the state of computer based information systems for medicine in the United States listed 73 projects in hospital and office information systems, 51 projects in computer-aided diagnosis, and 28 projects in storage and retrieval of medical documents and information. The Lockheed experiences of the late 1960s resulted in the Technicon MIS, one of the few surviving hospital information systems.

In the early 1980s, microcomputers and minicomputers began to be connected to each other and to mainframe computers by networks which permitted multiple modules, applications, and programs to work in the system at the same time. The larger medical centers, which had implemented a hospital information system, added an office information system for their associated clinics; and clinics with an office information system expanded the system to communicate with their affiliated hospitals.

Effects of Legislation and Funding

In September 1960, James Shannon, the Director of the National Institutes of Health (NIH), established an Advisory Committee on Computers in Research, and this committee was given the basic function of a study section to review research grants dealing primarily with the problems of biomedical computing. It was this Committee that was responsible for the initial funding of many of the leading academic centers in medical informatics in the United States. In 1963, NIH initiated its sponsorship of life science computer resources and the funds available that first year were over $8 million.

During this same period of time, the second half of the 1960s, under the Heart, Cancer and Stroke Act of 1965, Regional Medical Program (RMP) grants were authorized by the U.S. Congress. By 1967 there were established 54 computer-based Regional Medical Programs, including clinical laboratory systems, multiphasic testing systems, clinical research databases, and registries.

In 1968, within the Health Services and Mental Health Administration (HSMHA), the National Center for Health Services Research and Development (NCHSR&D) was organized, and it also supported research and development programs for computer applications to medical care.

Thus, through the 1960s, massive increases in the budgets of the National Institutes of Health resulted in a great surge of activity in medical research. The 1960s were outstandingly productive years for research and development of medical informatics in the United States as parallel streams of substantial funds came from NIH, RMP, and NCHSR&D. However, in the early 1970s, an abrupt curtailment of growth occurred in the NIH computer resources program, which Raub at NIH explained as reflecting "the interaction of two basic forces: (1) the overall slowdown in Government research spending and (2) the rather cautious attitude on the part of the mainstream of the biomedical research community as to just how far the computer can (and should) penetrate their discipline."

Although the National Library of Medicine initiated some training programs in informatics in the 1970s, it was not until the 1980s that NLM and its Lister Hill Center for Biomedical Communications began to actively support research and development in medical informatics.

The four decades, 1950s through the 1980s, were remarkable not only because of the rapid diffusion of technological innovations, but because of the important changes in the United States in legislation and in the financing of health care. Health became a major potential political issue when in 1953 Oveta Culp Hobby became the first Secretary of Health, Education and Welfare. In the 1950s, only about 50 percent of the U.S. population were covered by some sort of voluntary health insurance. In 1965, President Johnson signed the Medicare Act. The advent of Medicare and Medicaid extended health care to the elderly and indigent; so in the 1980s almost everyone had some type of health care coverage. Under this type of arrangement, third party payors and health insurers clearly helped finance medical technology. In the 1950s, national expenditures for health were about 3 percent of the national gross product, or about $100 per person per year; in the 1960s these expenditures were about 5 percent or $150; and by 1987 health expenditures had risen to 11 percent or almost $2,000 per person per year.

In the 1960s and 70s it seemed as if the U.S. Congress extended itself to do as much as possible to conquer important diseases, and new institutes were added to NIH for this purpose. However, by the 1980s the increasing expenditures for health care became a great national concern, and efforts to control the costs of care became a matter of high priority. In the early 1980s, the Health Care Financing Agency (HCFA) instituted for hospital patients fixed Medicare payments by diagnostic related groups (DRGs) based upon International Classification of Diseases (ICD) Codes. This produced in every hospital in the United States that accepted Medicare patients a rapid and often a major change in its hospital computer system so as to be capable of collecting the necessary data to satisfy Medicare billing requirements. Later in the 1980s, HCFA began to require physicians to similarly provide ICD codes on their payment claims for the diagnoses of Medicare patients. It became very clear that HCFA, by its dramatic actions in the 1980s, was a powerful force in the diffusion of hospital information systems in the U.S.A.

The Health Maintenance Organization (HMO) Act of 1973, generally based upon the success of the Kaiser Permanente Medical Care Program, led to a rapidly increasing number of prepaid group practice programs in the country. With the increasing costs of medical care, and competition between medical organizations in the 1980s, there resulted an increasing industrialization of medical care and the formation of medical conglomerates; which provided the stimulus for evolving multi-facility medical information systems.

The Role of Professional Organizations

By the late 1960s, many of the larger medical professional organizations had initiated special committees on computer applications. As one example, in 1966 the AMA sponsored a conference on "The Computer and the Medical Record"; and in 1969 the AMA formed a Committee on the Computer in Medicine.

The largest annual conference in the USA entirely dedicated to medical informatics has been the annual Symposium for Computer Applications in Medical Care (SCAMC). The first SCAMC was held in 1977; subsequently an annual fall SCAMC has been held either in Washington, D.C. or in Baltimore. The SCAMC programs have been very successful; and the annual SCAMC proceedings are the most efficient way of reviewing the progress of medical informatics activities in the USA since 1977.

The first professional organization in the USA with the primary goal of furthering medical technology systems, including computing systems, was the Society for Advanced Medical Systems (SAMS), incorporated in 1968. The first professional organization in the USA committed entirely to medical informatics was the Society for Computer Medicine (SCM), organized in 1971. SAMS and SCM each had fewer than 500 members and held separate annual meetings in the 1970s. It became increasingly evident to members who belonged to both boards of directors that there was considerable duplication of effort for many common objectives. The result was a merger of SAMS and SCM in 1981 to form a new organization called the American Association for Medical Systems and Informatics (AAMSI). AAMSI's membership grew to almost 1,000 and it conducted annual spring congresses on the West Coast.

In 1985, in response to the perceived need by specialists in this new field to achieve some formal professional recognition, the American College for Medical Informatics (ACMI) was established. The College meets regularly at the time of the spring AAMSI and the fall SCAMC meetings. The College elects its Fellows from all health care professionals who have a doctoral degree and have made important contributions to health informatics.

During 1986 and 1987, it became obvious to all involved that there was considerable overlapping of the memberships of the governing bodies of AAMSI, ACMI, and SCAMC. After a series of meetings between the officers of the three organizations, a merger was approved to form a new single organization called the American Medical Informatics Association (AMIA), which in November 1988 was incorporated in the District of Columbia. Dr. Donald Lindberg was elected its first president for a 1989-90 term of office. AMIA's board plans to expand the former

AAMSI's membership to several thousand, continue the large annual fall symposium In Washington, D.C., conduct more focused smaller spring meetings, and allow the American College of Medical Informatics to continue to remain functionally autonomous within AMIA.

Why Should Dentists Be Interested in Medical Informatics?

The dental profession should study and build on medical informatics for the following reasons:

(1) A good medical or health information system can handle data coming in from physicians, dentists, or nurses; from a psychiatrist or psychologist, from a physician or dental oral surgeon. It is a basic principle of an information system that it is independent of its data content.

(2) Dental information systems must provide services similar to medical information systems for patient identification and registration, appointment scheduling, and billing and accounting, and for clinical data relevant to the patient's history, diagnosis, and therapy, lab tests and x-rays, and for any followup.

(3) Dentists and physicians exchange data for oral medicine and surgery, for medically compromised patients with conditions such as diabetes and valvular heart disease, and for other reasons.

How Can Dental Informatics Benefit from Medical Informatics?

Reflecting over the past four decades of medical informatics, I shall focus on patient care since I believe that is the primary goal of medicine, and medical research and education are to support that goal. The major impediments to the general acceptance of medical information systems have been and still are the following:

(1) The computer-stored patient care record is incomplete and discontinuous over time. There is lack of integration of patient data from different patient care modules, although networking technology is now available. Office information systems are being integrated with hospital information systems. Fortunately for dental informatics, the patient record is a more specialized set of data and should be easier to manage.

(2) Methods for entering data from both professionals and patients are generally unacceptable. Patients' histories and professionals'

examination notes are usually entered into the computer by clerical intermediaries. Voice input and output technology is becoming available for those who will not use keyboards for data entry.

(3) There is inadequate standardization of medical terms, procedures, and codes. Efforts to agree on a uniform medical language, terms, and codes are underway.

(4) There is a lack of adequate clinical decision support, for both diagnosis and treatment. It is encouraging that better expert systems are now becoming available.

(5) There has been less than enthusiastic support and cooperation from individual health care professionals. Hopefully, more acceptable computer terminals and better computer-stored patient records will help health professionals to use computer-based medical information systems.

How Should Dentists Proceed in Order to Advance Dental Informatics?

The goals advanced for dentistry at this conference are very worthy ones, and to carry them out I suggest you consider the following phased-in approach, much of which you are already doing:

First: I suggest you define every one of your objectives for dental informatics very precisely and in great detail. Just as the primary goal of medical informatics for medicine is to improve patient care, so I believe the primary goal of dental informatics should be to use this new field to continually advance and improve dental patient care. Your objectives should define how you want dental informatics to improve each branch of dentistry for more effective prevention, diagnosis, and treatment of patients. When you have defined the specific objectives and detailed sub-objectives for patient care, then define the objectives of dental informatics for dental research (such as research clinical databases) and for dental education, both undergraduate and postgraduate, in order to support and advance dental care.

Second: Study what medical informatics has done for each objective which is similar to yours and apply any lessons relevant to dental informatics. Learn from medicine's strengths and weaknesses, successes and failures, so that dental informatics can exploit medicine's successes and not repeat medicine's mistakes.
Third: Develop three coordinated sets of plans: a short term action plan for the immediate five years, an intermediate term plan for years 5-10, and a long-range strategic plan for years 10-20. You will have to

accept the reality that a program of this magnitude will be a continuing one for the next 10-20 years. You will have to set priorities for what you can do successfully in the allotted time with the allocated funds.

These plans should include:

(a) Defined functional requirements for dental informatics; i.e., exactly what do you want dental informatics to do for patient care, for research, and for education?

(b) Detailed technical specifications; i.e., how you plan technically to satisfy each functional requirement?

(c) Organizational requirements; i.e., how will you mobilize your various dental organizations to participate?

(d) Financing requirements; i.e., after you estimate costs (money and personnel), and set priorities for the immediate five years, how will you obtain the necessary financial support for your plans? Consider applying for a planning grant for the initial development of your three plans and then seek funds to support the higher priority projects for the first five years.

Fourth: After obtaining five-year funding commitments, implement your five-year plan.

Fifth: Periodically (i.e., at least annually) evaluate your progress, and adjust your plans to accommodate new requirements and technological innovations. Medicine and dentistry are very dynamic and you must allow flexibility in your planning to accommodate constant change.

Drs. Marion Ball and John Zimmerman have written that by the end of the 1990s, seven out of ten dentists would be using computer technology. I trust and hope that in the coming decade dental informatics will satisfy all your professional needs and expectations.

[The historical review in this article is abstracted from "A History of Medical Informatics in the USA" a book in preparation by Dr. Collen under contract with the National Library of Medicine.]

3- Nursing Informatics: How It Evolved and Its Current Status

Marion J. Ball

Nursing informatics began over ten years ago and has developed organizationally over the 1980s. In establishing itself as an internationally visible discipline, nursing informatics benefited from the assistance of the International Medical Informatics Association (IMIA) and the Symposium for Computer Applications in Medical Care (SCAMC). Other developments have been fostered by the nursing profession itself. Clearly, nursing informatics serves as a model for other health professions seeking to introduce computer technology into their practice. Lessons learned from the growing pains of nursing informatics can be applied to the evolving discipline of dental informatics.

The Role of Professional Associations

In 1980, Dr. Kathryn Hannah, who in 1976 authored a paper in *Nursing Outlook* setting the course for nursing informatics in North America, called a meeting of nurses present in Tokyo at MedInfo. To her amazement, seventy nurses at the conference, sponsored by the International Medical Informatics Association (IMIA), responded and showed great interest in creating some relationship with IMIA on behalf of nursing. Today, Dr. Hannah (who has contributed greatly to this author's education) is Director of Nursing for Systems, Research and Education at Calgary General Hospital and Professor in the Faculty of Nursing at the University of Calgary in Canada and an internationally recognized leader in nursing informatics.

The overwhelming interest in Tokyo led Maureen Scholes of London and a contingent of British nurses to host an international conference to address the impact of computers on nursing. With the help of a well known medical informatician, Dr. Barry Barber, Ms. Scholes held the first meeting of a special international interest group in England in 1982, along with her colleagues and with the continuing guidance of Dr. Hannah.

Jointly sponsored by IMIA and the British Nursing Society, the forum demonstrated the need for a formal international exchange of information and ideas on computers and information systems as they are utilized by the nursing profession. For this reason, at the MedInfo meeting held in Amsterdam in 1983, the IMIA Working Group on Nursing Informatics held its inaugural meeting.

IMIA, which has played a prominent role in promoting computers in health care nationally and internationally, began in 1960 as a technical subcommittee of the International Federation for Information Processing (IFIP). Technical committee TC4, as it was then called, matured over time and in 1979 became a Special Interest Group known as the International Medical Informatics Association (IMIA).

IMIA now controls its own budget and is responsible for directing activities related to working group conferences and its relationship with other associations. A worldwide representative federation of national societies for health informatics and affiliated organizations, IMIA does not have individual members. Each country has one designated representative who has one vote, but there may be several delegates from a specific country who act as observers.

In the international arena, IMIA's prime function is the dissemination of information regarding health information processing. This is accomplished through four major areas of activity:

- **MEDINFO (World Congress on Medical Informatics).** Held every three years, these congresses provide an overview of the current state of the art of health informatics. Since the first in Stockholm in 1974, they have been held in Toronto in 1977, Tokyo in 1980, Amsterdam in 1983, and Washington in 1986. The year 1989 saw two MedInfos, one in Beijing, China, in October and a second in Singapore, Malaysia, in December.

- **Working Groups.** IMIA sponsors working groups (eleven at the moment) on very specific subjects, such as nursing informatics, hospital information systems, confidentiality and security, private practice office systems, etc. Of special note is the fact that in 1989, just before this conference at the Aspen Institute, IMIA officially designated Dental Informatics as its Working Group 11.

- **Publications.** To share the results of the congresses and working groups, IMIA prepares proceedings and special documents, published by North Holland. There are now about twenty such publications, based upon meetings held over the last ten years.

- **International Associations.** IMIA also provides input to such organizations as the World Health Organization, the World Medical Association, and the Pan American Health Organization.

In the United States, nursing informatics has also benefited from its association with the Symposium of Computer Applications in Medical Care (SCAMC). Dr. Virginia Saba was instrumental in establishing the nursing presence at SCAMC, which has endorsed active nursing sessions since 1981.

The nursing community has also advocated nursing informatics within its own professional associations. The American Nursing Association (ANA) has established a council on computer applications and the National League of Nursing (NLN) has instituted a council on nursing informatics. Sigma Theta Tau, the International Honor Society of Nursing, recently introduced awards recognizing individuals who have furthered the use of information technology in support of nursing care.

ANA and NLN have actively worked to further nursing informatics, both nationally and internationally. With their counterparts from other countries, they provide representatives to the IMIA Working Group on Nursing Informatics which sponsored the second International Symposium on Nursing Use of Computers and Information Science, held in 1985 at the University of Calgary in Canada.

In the spring of 1988, with the Irish Nursing Board and Noel Daly as host, the Third International Symposium on Nursing Use of Computers and Information Science drew over a thousand nurses from around the world to Dublin. Like its predecessors, that conference was followed by a small invitational Working Conference that looked at the future of the use of computers in nursing practice, education, research, and administration. As reported in *Nursing Use of Computers and Information Science* (North Holland), the focus of these Working Conferences is to:

- Identify how nurses use information.
- Determine unmet information needs of nurses.
- Generate directions for future research related to the use of computers and information science in nursing settings.
- Determine priorities for future research and development related to the use of computers in information science in nursing settings.
- Promote international networks for the exchange of ideas and information among individuals having a common interest in the use of computers and information science.

The fourth international symposium will take place in Australia in 1991. Estimates are that, once again, more than one thousand nurses will attend from around the globe.

Publications and Programmatic Developments

The field of medical informatics is acknowledged by a growing body of publications, including both books exclusively dedicated to the subject and articles throughout the nursing literature and in other health informatics publications. Notably, the *American Journal of Nursing* honored one text in the field with its 1985 Nursing Book of the Year award, and the first professional refereed journal in the field, *Computers in Nursing,* reaches more than 18,000 subscribers.

Nursing informatics is also being formally recognized through programmatic efforts in North America and elsewhere. The first nursing informatics degree in the world is offered by the University of Maryland at Baltimore under the visionary leadership of Dr. Barbara Heller. In 1988, this program made possible certification in nursing informatics within a master's track in nursing administration. From thirty-five to forty students are now enrolled in the program.

Conclusion

The evolutionary course of nursing informatics, as it has moved to become a recognized discipline, should guide the dental profession in developing dental informatics. Benefitting from the experiences of another health profession, dentistry should be able to compress into a few years the progress which took nursing over almost a decade and medicine even longer, as the first laborer in the vineyard of informatics. Clearly, dentistry has the ability to learn from the mistakes of its fellow health professional colleagues and to be a viable and recognized discipline within the next three to four years.

4- Dental Informatics: An Overview

Howard L. Bailit

Today, I plan to discuss what it is going to take for computers to have a real impact on the practice of dentistry. I will say some things that are provocative and that you may not agree with, but that is what a conference of this nature is all about.

First, I will examine the structure of the dental delivery system: what does it look like, and what needs must an electronic information system meet? Then, I will discuss four issues: (1) current status of computer use in dentistry; (2) information system requirements; (3) some applications of dental informatics; and (4) practical considerations.

Dental Delivery System

There are about 140,000 practicing dentists and maybe 600,000 dental staff in the U.S. About 70 percent of dentists are in solo practice, and 15 percent are in two-person practices. Only a very small number of practitioners are involved in group practices with three or more dentists, and group practices are growing very slowly. A related factor is that 85 percent of dentists are generalists. The number of dental specialists is increasing, but will only get to about 20 percent of dentists by the year 2000.

Looking at the basic operation of dental practices, they require a relatively low capital investment to get started. For example, a general practice can be started with an initial expenditure of under $100,000. Another interesting fact is that there is fairly high turnover in dental practice staff; it is estimated that close to 50 percent of staff are lost within two years. This is important when staff training needs are considered.

The dental practice sector is going to get smaller because of a large reduction in the number of dentists. However, practicing dentists are going to be more affluent; the evidence suggests that dentists' incomes will increase significantly over the next few years, especially after the year 2000.

From the foregoing, it is clear that dental practitioners are a small group declining in size; few dentists are in group practice; their practices require little initial capital investment and have relatively high staff turnover. This means that successful computer systems must be relatively inexpensive and very user-friendly.

The second major point I want to make comes from talking with individuals in industrial organizations who are experts on increasing productivity in large companies. These specialists say that not much can be done with system enhancements to increase productivity in very small firms because the drive and efforts of the individual entrepreneur--in this case, the dentist--account for 80 to 90 percent of the firm's productivity.

In my view, the current structure of dental practice sets bounds on what can be reasonably accomplished by introducing information technology into dental offices. Will computerized records lead to huge gains in efficiency in the quality of care provided in solo practices? The Information Age is just beginning, and there is not enough experience in applying technologies to know what impact they will have. Hopefully, it will change dental practice, and improve it for all involved--the patient and the dentist.

System Requirements

What kind of information system will be successful in the dental practice environment? First, the system must integrate fiscal and clinical management. Two separate systems are not going to work, because they will require double key stroking patient name, social security number, address, and so on each time a record is created. Second, it would be advantageous to link third party payors to databases of the type mentioned by Dr. Lindberg. Many payors are now developing systems that electronically process reimbursement claims directiy. Third, the system should provide for a clinical decision support system that is fully interactive. Finally, the system should be easy to use. With 140,000 practitioners widely dispersed across the country and frequent staff turnover, time and a successful dental information system must be easy to learn, utilize, and maintain.

Status of Computers in Dentistry

What is the status now of computers in dentistry? Most dental schools use some sort of fiscal management software in their clinics and in teaching students practice administration; and there are a few schools like the Medical College of Virginia and the University of Texas at San Antonio where there is some research and software development going on. I would estimate, however, that there are only about ten dental schools where there is any significant effort in the latter area. Moreover, no more than five people in the whole country have degrees in dentistry and the computer sciences. In the practice sector, some dentists use computers for patient billing and accounting, but for little else.

Applications of Dental Information Systems

What are the different applications of dental information systems in the real world of practice? Just in terms of data storage and retrieval, a computerized dental record may have little impact on solo practice efficiency. There is the problem of radiographs, study casts, and the like. Dentists will require records with x-rays and forms for laboratory prostheses. Also, for the average dental patient there is relatively little information in the record because most do not receive a large number of complex services by multiple providers, or have a wide variety of laboratory tests. Another interesting thing about dentistry is that the care received is clinically visible. In most cases, a long history is not needed to figure out what is happening to a particular patient. Dental health status can be assessed by clinical examination so that a battery of laboratory tests is not often indicated.

Thus far, I have talked mostly about the problems which may be encountered when informatics is introduced to dental practices. Let me turn now to some of the potential benefits. One advantage is to have access to data on aggregates of patients. The average dentist has little idea what is going on in his or her practice at the aggregate level, either administratively or clinically. This is because data have been too expensive to collect and analyze. For example on the fiscal side, very few dentists really know what their costs and productivity are. As a result, they simply do not know how to price services relative to their cost of production, or what the market will bear in their area. Thus, there is a tremendous opportunity for some sophisticated work to be done by analyzing aggregate practice data.

Clinical decision support systems are another area where dental informatics has excellent potential. As currently conceived, they can provide the dentist with a large base of factual information concerning diagnosis and treatment for instant electronic retrieval and thus assist him or her in delivering a higher quality of care. With a computerized fiscal and clinical record system, there are a number of ways to improve patient care. Some of you at this meeting are now working on clinical decision support systems. Unfortunately, I do not know of anyone working on fiscal decision systems. In part this is because few investigators in dental schools have the appropriate background and training. These fiscal decision support programs could be of significant value to dentists, organized dentistry, reimbursement agencies, dental schools, and so on.

Another area in dental informatics that will eventually have a big impact is computerized CAD-CAM systems for restoring teeth. A system developed in France now sells in the United States for between $70,000 and $150,000. This system can produce a crown from start to finish in about an hour and a half; that is from the time the patient is anesthetized to the time the patient leaves the office. Certainly, this is an important change in dental technology, and as these CAD/CAM systems become less expensive and more refined, they are likely to have a major impact on the clinical practice of dentistry.

I also understand that research is now going on with the use of robots to prepare teeth for restorations. This is not "star wars"; this technology is becoming a reality. Computerized systems also are available for determining occlusal forces; called T-SCAN, this system provides more accurate and sophisticated information on the masticatory forces in the mouth that apply when a prosthesis or a filling is inserted, or when there is need for an occlusal equilibration. These are very interesting developments in dentistry, making a science out of what is now primarily an art.

Practical Considerations

In closing let me offer some practical considerations that can act to constrain the use of computers in dental practices. It is important not to get too euphoric about the future of this area, and to appreciate the difficulties that must be overcome.

- Dentists must be trained to use computer-based information systems. So far, little is being done in dental schools or in continuing education programs to prepare dentists for the use of this technology. On the other hand, the dental students of today are computer literate, an asset dental faculty should circulate and restructure their curricula and teaching methodology for.

- Dental practices have a major problem with staff turnover that will have to be addressed before there is a wide dissemination of computers. Dentists are going to need a core group of employees who are highly trained and who will remain with the practice.

- The system for distributing and maintaining software needs to be developed. Major software companies have not invested in dental and medical practice systems because of the difficulties of making a profit in this market. IBM, EDS, NDC or some other large company needs to come up with a strategy for servicing this segment of the market.

- Hardware costs need to be reduced. Even in solo practices, dentists will need at least three terminals to use computers efficiently. For the average small practice this investment in hardware may be a problem.

Finally, I have come to the conclusion that dentistry cannot solve these problems alone. That is, dentistry offers too small a market for the large investment needed in software and distribution systems. Perhaps the answer lies in having a general practice information system that can be easily adapted for use by physicians, dentists, and other health practitioners. In this way there may be large economies of scale, a critical issue for any company thinking of investing in this area.

In sum, for the reasons discussed the dissemination of computer-based information systems to dentists is likely to proceed slowly. At this time dental schools have the opportunity, indeed the responsibility, to provide students with basic courses and clinical experiences with computers and clinical decision programs, and to undertake the basic and applied research in dental informatics needed to advance this field.

In my view, this meeting will be seen by future generations as a milestone in the new and developing science of dental informatics. My thanks to the planners of the meeting, to Westinghouse, to the AADS, and to the University of Maryland for making it possible. I wish you well as this exciting new field gets underway.

5- The Problem-Knowledge Coupler: Applications in Health Care Delivery

Lawrence L. Weed

As we formulate and solve problems, it is not easy to couple medical actions on a unique patient to the best thinking available in the textbooks and journals. In fact, when many variables are involved, common sense and studies in psychology tell us that the unaided human mind cannot rigorously couple thought to action much of the time. Passing examinations for knowledge at one time in life, or taking a course in decision-making, cannot alter this basic reality; nor is it altered by the analyses of how the unaided minds of "experts" function. It is true that one human being may be more "expert" than another in solving a complex problem, but that small difference may be irrelevant to what the patient expects and deserves. Let us review what the problem-oriented record in medicine has shown us in this regard, and what some specific new tools can do to help us. Let us then review the tricks that the unaided mind will play upon us if we persist in current educational methods and examinations, and if we continue to encourage the unaided "credentialed" human mind to try the impossible at the time of action. We will conclude by examining the Problem-Knowledge coupler as a means to assist physicians, dentists, and other healthcare providers in managing the ever enlarging body of knowledge essential to proper patient care.

The problem-oriented system requires and reveals:

1. A defined database for each group from which a complete problem list can be derived.

   The unaided mind, working with a dictaphone or blank sheet of paper, rarely achieves this first step in a thorough and reliable manner.

2. A complete list of problems that accounts for all the abnormalities in the database.

   Without guidance of a very rigorous and defined sort, a complete problem list is not achieved in most environments. Frequently, all of the data in the database are not used to achieve the maximum synthesis that is possible; the unaided mind does not see many of the significant relationships among the various bits of data, and what synthesis there is may be unjustifiably biased by the specialty training and parochial experiences of providers. Furthermore, since a complete list of problems is not made available to all providers on all clinical encounters, medical care activities are neither coordinated nor cumulative.

3. Organized planning for each problem that accounts for:

   (a) other problems and data on the patient

   (b) best known options from the literature for solving the problem

   (c) needs and goals of the patient and his/her family.

   Time after time it has been observed that the unaided mind using current written records is simply unable to recall all of the necessary data on the patient, unable to keep up to date on all of the options, and unable to integrate them systematically with the patient's personal desires and goals. Indeed the patient's role in his/her own behalf has been grossly neglected.

4. Titled and numbered notes on each problem that coordinate multiple providers and provide feedback loops on action taken.

   It has been shown repeatedly that there may not be disciplined implementation of a plan once it has been formulated, or intelligent modification of a plan based on additional data. Providers do not communicate effectively and parameters are not followed meticulously and recorded accurately. At the time of action, clinicians try to deal with many variables extemporaneously, and they frequently fail to do this rigorously.

So, what I want to talk about today is the basic issue of getting large quantities of biomedical knowledge and information concerning patient care better organized and more readily accessible through the use of different tools and premises.

A basic premise has been that "education" enables us to couple the best available knowledge and thought to everyday action. We "learn" by being "taught" in school, and then we expect the unaided human mind to recall and process vast amounts of information, all "in the same breath" at the time of action. There is a process of stuffing by the teacher and cramming by the student. These are followed by regurgitation in response to exams, from which come credentials. Thus prepared and anointed, today's health professional is supposed to go out into the world and recall and process the right variables every time a patient is seen. That is what the premise has been, and we all know that the "voltage drop" is enormous from the best that is known to what is done for the average patient. Clearly, we make such enormous assumptions that the public thinks those credentials mean something they may not mean. This is why you will hear me talk about "educational malpractice." Those diplomas could not mean what the public thinks they mean. Moreover, think what has been done to the science of medicine and health care. If each action does not represent the best thinking each time, then we cannot meaningfully study the results of our actions (outcome studies) to correct our misconceptions and update our knowledge. Rigorous feedback loops do not exist. In any memory-based system involving so much complexity, "inputs" cannot be controlled, so "outputs" cannot be rigorously interpreted.

Another premise that must go is one which says we construct our examinations so students are tested on what they know. We should never examine students on what they <u>know</u>. The true test is how well the student uses modern information tools to apply the best available knowledge to unique problem situations. As long as schools test students on what they know, little will change; people behave according to how they will be tested. We should determine what we want to do (provide the best possible patient care with the most modern tools and up-to-date knowledge), and then shape our examinations so they measure what we want to see students do as well as how they approach patient care.

In reflecting on what I have described at the outset about what the problem-oriented system requires and reveals, I concluded that professionals cannot be merely dismissed as being careless and sloppy in their approach to patient care. When we really started to look at what is required, it became obvious that the human brain simply cannot absorb, retain, and recall all of the information required to be a totally competent health professional. Could the human mind possibly get at a defined database every time; set a goal for the problem; know the disability and its status; know which signs and symptoms to follow and what complications to watch for? Our response was the problem-oriented patient record which has since been computerized for use in a computerized ward with touch sensitive screens. There were no paper records in that ward. If a patient came in with a mediastinal mass, 28 causes would be displayed on the screen along with detailed information about each of the causes. There would be 55,000 displays and 10 choices per display. It was an enormous amount of information; however, when the human memory problem is resolved, a processing limitation was uncovered that was worse than the memory constraints.

After one is confronted with a certain amount of information, what happens? What will nurses do on an intensive care unit until a certain number of red lights go on? They shut them all off and have a cigarette! If you give the student too much homework to do--if you go above a certain threshold--what will he do? He will go to the movies and ignore the work! Unfortunately, medical and dental schools set unreasonable goals for what the human mind can do. Information overload in these institutions has reached the point where the student will stop thinking, will regurgitate and then forget. To quote Santayana, "For too many people, going through life is a slow movement from the forgotten to the unexpected!"

To illustrate further, consider this. There are 70 causes of chest pain; some of them are heart, some are GI, some might be orthopedic (e.g., a thoracic disk), or maybe hematological. The most important decision patients make is the door they walk through to seek professional attention. As Mark Twain said, "To a kid with a new hammer, everything's a nail." There is the story of a woman; it took 12 weeks for her to get an appointment in Boston to see a specialist at the Massachusetts General Hospital. When she got there, she said, "Doctor, I'm so glad I finally got to see you. I understand you're the best doctor in Boston for what I have." The physician said, "Lady, I hope you have what I treat." Psychologists have done studies to show that the human mind falls apart after five to seven variables. Our patients are literally hundreds of variables crossing all our specialties.

Problem-Knowledge Coupler

Clearly, we need a process in medical and dental practice through which we can selectively tailor our knowledge armamentarium to each patient's unique set of problems. We can do this through development and utilization of the "Problem-Knowledge Coupler," a computer program which, on the basis of facts obtained from the unique patient, mobilizes information from the literature on a given problem and then presents it to the provider and patient. Each bit of information on the patient is "coupled" to the relevant bits of information from the literature to assist the health professional with clinical decision making.

Let us review how the Problem-Knowledge Coupler works. Having been presented with a clinical problem, the computer then asks questions about the individual patient. Each answer triggers within the machine (computer) a translation of positive responses into a list of hypotheses, i.e., all possible diagnoses or management strategies suggested by the positive responses. The memory and response time of the machine allow it to consider 40 causes or management strategies as reliably as five - something the unaided human mind cannot do. In other words, it will not limit the number of hypotheses that it will consider merely because it cannot remember them all; nor will it skip some hypotheses because they are rare and not probable. Furthermore, the answers to the early questions do not in any way prematurely halt or direct questions, or bias the computer's responses to later questions. After checking 50 to 200 history and physical findings in the patient, the machine will then tally for each cause or management strategy the number of suggestions for each, based on the information (i.e., the array of "propensities") obtained from that unique patient. In seconds, it will then confront the provider AND the patient with a print-out on the screen or on paper of the causes and/or strategies to be considered, and the particular characteristics of that unique patient that suggested each. Furthermore, it will enumerate "propensities" and relate them to the total number the machine has stored for each cause or management strategy.

For example, for the problem of hypertension the computer might print out that a patient manifests six out of seven "propensities" for polycystic kidneys, one out of five for pheochromocytoma, and so on. Many possible diagnoses, for example, one such as coarctation of the aorta, may not appear at all, because that particular unique patient has none of the propensities, such as diminished or absent femoral pulses, that suggest this lesion. The user can get further aid from the total computerized problem-oriented system on how to pursue each suggested diagnosis (diagnostic hypothesis) in greater detail. Such an approach helps us find the rare (i.e., the highly improbable) diagnosis as securely as the common one (i.e., the highly probable).

In the presence of the Problem-Knowledge Coupler, the user is not electronically overwhelmed with massive amounts of database information or with display after display from the entire literature about hypertension or abdominal pain. Rather, he/she is confronted only with the content from the literature which is relevant to a unique patient. In other words, why should a busy practitioner be burdened with a view of the entire body of the latest information on hypertension, or coarctation of the aorta, if it is inappropriate in the absence of suggestive propensities in a patient? Knowledge overload without the time or intellectual capacity to sort it out on "spur of the moment" action can be as dangerous as ignorance.

If there is still uncertainty after the use of the Problem-Knowledge Coupler, probabilities and the necessary mathematical calculations can be applied as needed. In many cases, these will not be necessary, because getting command of many simple elements in the aggregate can be extremely powerful in solving problems. With the Problem-Knowledge Coupler we have the means to do that. And when the Problem-Knowledge Coupler leads to ambiguous and confusing results, the limitations of human experts are not likely to resolve such ambiguities. After all, what we have done is to couple rigorously the findings in a unique patient to what the experts have painstakingly put into their books and articles about those findings. We have avoided the "voltage drop" based on limited human faculties at the time of action.

Where expert help is needed is in the collecting of reliable data to "feed" into the Problem-Knowledge Coupler. Its output is only as reliable as the bits of data it receives as input. As with the analyzer in the clinical chemistry laboratory, a bad specimen often leads to inaccurate results. Reliable outputs from the Problem-Knowledge Coupler can be the basis for studying what is in our literature which is most discriminatory and productive for solving problems. In this respect, the medical librarian is a valuable resource for developing the programs for the Problem-Knowledge Coupler.

A review of the serious mistakes in medicine, ones for which we have many regrets, shows that many result from losing sight of simple but significant elements. And these simple elements are as powerful for finding the rare as they are for the common. Our oversights often have nothing to do with ignorance of some sophisticated new technique, or our inability to apply the very latest in decision theory. Statistics on thousands of medical malpractice cases show that failure to identify or use correctly a simple fact on physical examination was the principal basis for error. In this regard, although the Problem-Knowledge Coupler is just one part of a total computerized problem-oriented system, it is a crucial part in harvesting the full benefits from the analysis of many simple elements in the aggregate.

Conclusion

Unfortunately, many people conclude from the above delineation of our failings that we need to teach problem-solving in medical and dental schools, and that more postgraduate education is necessary. The central question is not how you teach a single mind to solve problems better, but what is the best combination of system, machines, and specific types of people for solving any health care problem in the context of an individual patient's life. Once we see the problem in this way, we expend energy and resources in a very different manner.

The switch to new premises and new tools for education and care will not be easy, but once we make the switch, we shall find that powerful tools like the Problem-Knowledge Coupler are useful, even essential, in many areas besides health care.

Part 3-Workshop Discussions and Recommendations

Introduction

The dominant theme of this conference was the need to identify strategic issues for dental informatics defined in its broadest terms and therefore lay the foundation for a national strategic plan for dental informatics. By identifying the strategic issues, e.g., key questions, areas of concern, and areas for future development, the professional associations and dental organizations can develop individual strategic plans that address their organizational goals and directions. A general and overall goal for the conference was to set forth recommendations for further exploration by the dental organizations. Each organization must then decide what issues most closely match their organization's goals and mission and incorporate those informatics issues into their strategic plan along with implementation strategies. As a long range goal the conference organizers hope to continue these meetings so that dental organizations have the opportunity to share their individual plans, find areas for collaboration, and identify gaps.

After hearing the overview statements made by the invited speakers as presented in the previous section of this report, the conference participants identified critical questions/issues facing the dental professional and discussed the potential impact dental informatics will have on these questions/issues and the future of the dental profession.

The participants then divided into three workshop groups, namely, education, research, and practice. Each group identified the questions in that discipline area and discussed initiatives already in progress and identified potential new initiatives. There was some overlap of topics between the groups, and there was no attempt to limit them. It is understandable that a topic such as expert systems may appear as a research interest, a tool with potential impact in dental practice, as well as an area that may be a useful educational tool and area for which training must be given in its effective use for patient care.

The workshop groups were structured to address functional areas in dentistry and not to specifically address technologies or systems. This was done in order to give the discussions an end-user focus. The workshop groups were to address the development and implementation of informatics tools and processes, not technological solutions looking for problems to solve. As noted earlier, the participants at this conference were dentists or affiliated dental professionals and not informatics professionals.

Critical Questions/Issues Identified

The following list of questions and issues spans a wide range, some of which could be addressed within the context of this conference and some which will continue as topics of discussion for many years.

- What does the ideal future look like for dentistry?

- What is the role of dental education in informatics? The tools and skills of tomorrow's dentist are the products of what is taught today's dental student.

- What new teaching methods/techniques should be introduced into the dental curriculum?

- Can informatics address the issue of better patient care as the patient population ages and undergoes more complex medical treatments?

- What is known about the practitioner/information interface? How do dentists access information? What kind of information do they need? Why do they access information? When do they need the information and how do they use it?

- How do dentists make decisions?

- What are the patients' information needs?

- What new information markets will be identified/created from growth in dental informatics?

- Should technologies and products be designed for the marketplace or the patient's needs?

- What is the role of dental organizations in software development, distribution, and maintenance in the development of other technologies and standards?

- Will the dental practice environment, dominated by solo practitioners who have little capital to invest and are not linked to hospital bases, impede the development of dental informatics?

- Should clinical databases comprised of private practice data be linked to dental school hubs?

- What can act as an information concentrator or hub? Should dental schools take the role of the community hospital?

- How does the profession identify or develop academic leadership for dental informatics?

- How does dentistry acquire funding for planning, research, and development in informatics?

- What is the planning cycle or process?

The discussions which ensued in each workshop group embraced three basic themes. Besides basic research building blocks (terminology, nosology, training researchers) dental informatics should develop information technologies for patient care and education. For example, research and development in patient care would design an integrated computerized patient record, improve diagnostics, and apply computer technology to restorative dentistry. Education applications would be directed to improving dental education at the pre- and postdoctoral levels and to facilitating the information/technology transfer.

A second theme was the need for support for these research and prototypical efforts. A convincing argument must be made that informatics is critical for quality oral health care. There is evidence that providing oral health care is becoming increasingly complex.

The third theme was the importance of cooperation. Cooperation has to be fostered within the dental community, between dentistry and other areas of health care, in the U.S. and internationally. Dental informatics though unique can adapt developments and approaches from other areas of informatics. In areas such as patient records, there must be compatibility across specialties, and with the patient's entire medical record. In educational applications, compatibility across institutions is needed.

In each of the workshop group reports that follow, the three themes, namely, cooperation, support for research and prototype development, and technological development, emerge repeatedly.

1- Informatics Applications in Dental Practice

Informatics Applications in Dental Practice

Several basic assumptions can be made when considering the relationship between the evolving field of dental informatics and dental practice. Dentists are independent practitioners of health care who are interested in providing the best possible care for their patients. The tools employed in providing that level of care should be the most up to date available so as to automate as much as possible the repetitious, tedious work that machines do best, thereby allowing humans to make clinical decisions and judgments, and build the relationships necessary to further advance the quality of patient care. The records resulting from patient care interactions are in themselves tools that should be used as the basis for research to improve the quality of care by furthering our understanding of oral diseases and their treatment.

State-of-the-Art: Practice Applications in Dental Informatics

Where in the delivery of patient care is there potential usefulness for information management technology? This workshop group agreed that there are three areas that can help improve dental practice and patient care: (1) patient record keeping; (2) fiscal practice management (i.e., business management) and (3) clinical decision support.

If patient record keeping is going to serve a purpose other than keeping a schedule of appointments, housing a treatment plan, and providing defense in liability litigation, then there must evolve a way to standardize data entry so information on patient care can be pooled and analyzed worldwide. Computerization of the patient record, electronic data entry by any one of several technologies, and standardization of terminology provide a natural avenue to this end. Development and evolution of this technology will provide the basis for gathering and analyzing large populations so as to monitor effectiveness of therapies and chart the course of oral and maxillofacial diseases. Access will have to be addressed along with other confidentiality issues involving release of information as data only. Further, with such a system patients should have some means to carry their electronic records with them wherever they go to seek professional care.

Fiscal management has been the most thoroughly developed area where informatics has impacted on dental practice. More than 300 dental office management systems are available today and dentists are often at a loss regarding how to choose between them. Most of these systems have been developed with little forethought and planning by simply rewriting standard business management applications. It is essential that the largest users of fiscal management systems, namely insurance companies and banks, become involved with developing fiscal management systems for dental, and indeed all healthcare, practice. It is only through attention on a regional, national, and international basis that issues of linkage and networking can be adequately addressed.

The goal for the fiscal management system in the twenty-first century dental office should be a smooth flow of data from the time the patient registers at the office through the appointment record entries, insurance claims processing, debiting the patient's bank account, and crediting the dentist's account. In this scheme, not one paper form should be filled in, and data already on hand in the patient's files at the dentist's office, the insurance company, and the banks should not be entered a second time. The only data necessarily entered at any appointment would be totally new information. Many of the standards exist today, and with proper application, today's technology could support development of such a system. Office staffing issues and practice and workload analyses could be readily addressed, not just locally, but nationally with the development of well-linked fiscal and business management systems.

Decision support technology (primarily software) that includes artificial intelligence, expert systems, and other evolving technologies should be looked upon as the vital underpinning that will make computerized record keeping and fiscal/business management systems live. Decision support will be vital in such major patient care arenas as diagnosis, treatment planning, and information retrieval, sorting, and utilization. Specifically, artificial intelligence systems will be sorting and comparing examination data with existing data banks to help practitioners make diagnostic choices while gathering and prioritizing pieces of information about patients and their peculiar situation, so that treatment planning alternatives are thoroughly explored. These computer systems will redefine the term "informed choice." Expert systems will be functioning also in coordination with data entry procedures making efficient use of information pieces so that dates, names, social security numbers, and historical data only need be gathered one time.

Numerous factors contribute to the growing need for dentists to depend on electronic databases rather than human memory. The database with which the dentist must work to resolve complex diagnostic and treatment problems is expanding at an exponential rate. Patients are taking and dentists are using more medications. Patients are ambulatory with more complex medical problems today than ever before and they carry such problems as compromised immune systems, transplanted or artificial organs, and other systemic conditions with them to the dental office. The need for consultation and referral is expanding as is the necessity to obtain complex laboratory tests. From the dental treatment side, periodontal diseases are being managed more individually as basic understanding of this disease expands. Dentists are performing more complex treatments "in house" than ever before. The use of new dental materials is requiring a vast, new, and frequently updated field of knowledge in an expanding number of individual clinical circumstances. For these and many other reasons, informatics will be playing an ever enlarging role in dental decision making.

Issues in Dental Informatics Practice Applications

Since there are so many areas where informatics technology can improve dental practice and patient care, it was decided to examine dental practice in the same manner that dentists approach patients. This organizational format was adopted in order to help focus dental informatics issues.

- Patient identification - administrative/management
- Problem identification - identifying all problems relevant to the health care of the patient
- Establishing the diagnosis
- Developing of the treatment plan
- Implementing the treatment plan
- Treatment outcomes
- Follow-up

Patient Identification

Practice oriented information management systems must address the issue of patient identification. Standardization of terminology and information collected and stored for individual patients needs to be addressed. A corollary concern is how information collected by dentists can and should be integrated into the general health record of the patient. Certainly the concept of a continuous, longitudinal, life-long health record including dentistry should be considered. The patient's desire for confidentiality and the providers' need to know are issues which must be resolved as well.

Problem Identification

In present practice methodology, the establishment of a working patient information database requires too much duplication in the process of data gathering and recording. There must be some means of centrally depositing and updating information, particularly in the area of health history, current diagnoses, allergies, medications, etc.

Use of information technology, including connectivity and decision support systems, should resolve duplication problems within the patient health database. Systems should include present and past health history, dental health history, present clinical problems, and laboratory, radiographic, medication and other examination records. Some questions related to the foregoing include: the information to be recorded, the role of standards for information management systems, integration of laboratory and other data, and data organization to provide the most meaningful patient profile.

With identification of all relevant clinical problems, regardless of their nature (dental or non-dental), expert systems should help by fitting the data into the total information package. Data should be entered only once with the system making maximal use of each piece of information.

Establishing the Diagnosis

Computerized diagnostic systems must support rather than supersede the judgment of the clinician. Decision support systems can maintain large databases on problems, make relationships, establish linkages, and compare and contrast information, but they should not be designed to make the final diagnosis. Liability issues will be important and should be investigated from the outset, e.g., what will the liability be for those using computer-based diagnostic systems and what standards will apply to those who choose not to utilize them?

Obviously systems must be tested for validity and standards established for reliability, construction, and continual updating. The issue of user confidence in diagnostic systems must be clearly addressed. Standards both in terminology and diagnostic approach must be developed and employed.

Developing of a Treatment Plan for Each Problem/Diagnosis

Educated, informed patients take more initiative in their own care. Systems that are developed for clinical practice should contribute to clear definition of treatment goals for each problem on the list. These systems must be developed to allow as much patient participation as possible in formulating the goals. This will lead to improved patient understanding and will encourage compliance with treatment. Treatment plans should be fully integrated and related to the diagnosis and goal for treatment. Clear enumeration of the pathway from diagnosis to therapy and treatment will greatly facilitate record audits for quality assurance. Additionally, computerization in establishing treatment plans will help enumerate the trends in therapy for various diagnoses across large patient populations.

Implementing of Treatment Plans

Treatment plans can be established and outlined according to goals and objectives, but often various factors interfere with implementation. This provides the basis for separation of treatment planning from implementation of treatment. Computer systems should aid in analysis of treatment plans for cost effectiveness, particularly in dentistry where there usually is more than one treatment for most clinical problems. For instance, it would be valuable to look at a large patient population and see what factors figured into implementation of partial denture treatments for missing teeth as opposed to fixed bridges. Standardization of terminology for diagnosis and treatment is a particularly important issue here.

Systems should be developed that fully utilize computers in implementing treatment. They should be designed to facilitate update and augmentation. Technology transferred from the research arena to practice should be facilitated and cooperative use of technology by practitioner and clinical investigator should be encouraged.

Follow-Up

Using computer systems in patient care will greatly improve patient follow-up and referral for consultation. Patients with their own electronic records will be able to carry complete information from one practitioner to another thus eliminating time consuming and costly duplication of examinations, laboratory tests, radiographs, etc. Informatics related technologies should be implemented for patient education and preventive programs. It is obvious that standards in terminology and system design will be important.

Treatment Outcomes

Evaluation of outcomes will help establish effectiveness of various treatment modalities. Networked computer systems will allow long-term, wide-spread evaluation of treatment outcomes. Parameters will have to be developed and standards agreed upon. Issues will arise as to how outcome data will be used. For instance, will providers be compared to one another or just to themselves, and will outcome data be used to establish standards of care? Outcomes will have to be defined in terms of patient satisfaction and in relationship to success in controlling disease. Computer systems will help establish and validate the uniqueness of providers and patient populations.

Information technology should not be employed in every case just because there are capabilities in this area. The task of dentists is to provide the best care possible for patients, and use the most up to date tools to accomplish that task. If modern information management tools will help accomplish this task in a way that meets patient care objectives, then they should be used to the fullest extent possible.

Workshop Group Recommendations

To stimulate and encourage informatics development in patient care activities, at least the following should be accomplished:

1. Research and development should be encouraged through a cooperative effort between industry and educational institutions to develop an ongoing program focused on the dental office of the twenty-first century. This project should include maximum use of information technology and would look at the entire spectrum of factors that are anticipated to impact on dental practice for the next decade and thereafter.

2. The insurance and banking industries should cooperate with dentistry to develop a program to study various forms of patient record keeping and database management. The focus should be on connectivity, simplicity, and economy of effort for users.

3. Efforts to survey practicing dentists in order to examine practice patterns in relation to informatics issues should be supported and encouraged.

4. A specific project should be addressed and developed to look at changes necessary in patient flow, personnel utilization, and office design to facilitate incorporating informatics related technology into dental practice.

5. A research project should be directed toward developing a totally integrated office computer system that is easily modified to accommodate technological advances. This system should completely integrate fiscal and business management, patient records, and clinical decision support.

6. A project should be undertaken to establish standards in terminology and computer equipment throughout dentistry.

2- Informatics and Dental Education

The primary task for this workshop group was identification of what is needed by dental schools to enhance the education of dentists who will function in new dental practice methods brought about by dental informatics. This new way to practice dentistry will require second generation dental records and decision support software which, while running in the background, will connect diagnostic findings and patient problems to a regularly updated knowledge base. It is anticipated that a significant proportion of the practitioners' continuing education effort will be directed toward practice-linked, at site, interactive courses and problem solving patient simulations. Also, this technology should be directed toward patient education. A new form of interactive patient education and shared approaches to oral and general health will emerge.

State-of-the-Art: Dental Informatics Education

In the early 1970's, the Health Manpower Act, designed to increase the number of professionals serving the healthcare needs of society, catapulted dentistry and the other health professions into the use of innovative teaching methodologies with the intent of training a greater number of students more efficiently and effectively over a shorter period of time. In the years following passage of this legislation, independent learning using a variety of forms of educational technology such as slide-tape presentations, television, filmstrips, and audio-tapes, proliferated in academic programs. During these years many of the dental schools, including Maryland, Kentucky, Texas, and Florida, had academic programs which had heavily integrated these forms of instruction into their curricula. In fact, as much as 85 percent of some courses were presented using independent learning as the primary means of instruction.

In 1975, the University of Iowa College of Dentistry began focusing on the use of computer technology in testing and created two programs, CATA (Computer Assisted Test Assembly) and CATAGEN (Computer Assisted Test Generation). These programs were developed realizing there was a large amount of faculty effort required to create and generate valid test items and examinations, and that computer technology had the potential to conduct this task more efficiently and effectively, thus providing faculty more time to concentrate on research and other teaching responsibilities.

The seventies also found other forms of communications technology being explored for use in dental education. The CTS (Communications Technology Satellite) Project was initiated in order to examine the use of satellites for teleconferencing. In this case, four dental schools were linked together to share continuing dental education presentations across the country through a project sponsored by the U.S. Department of Health, Education and Welfare, the U.S. Public Health Service, and the Health Resources Administration Division of Dentistry. A similar project followed this one in 1979, coordinated by the CTS sponsors and Indiana University, celebrating its 100th anniversary. In this case, the first dental school, Maryland; the newest dental school, Mississippi; and the celebrant dental school, Indiana, presented continuing dental education programs from their respective locations to 60 other sites including Puerto Rico and Hawaii. This was clearly the largest continuing dental education project up to that time.

The Plato Project coordinated by the University of Illinois was an innovative application of computer technology. This project included the development of 30 interactive "touch-screen" dental case simulations. They were produced from 1977 to 1980 through a grant from the National Library of Medicine and the University of Nebraska College of Dentistry, and were made available over the Plato network. The simulation strategy used at that time is still applicable today.

By 1983 there was a virtual technology explosion in the use of computer technology brought about by the microcomputer. As a result, the American Association of Dental Schools sponsored a program, "The Potential for Computers and Videodisc Technology in Dental Education" at the Annual Dental Deans Conference. This program presented a broad perspective on how computer and videodisc technology was making its way into the elementary and secondary schools, and gave dental deans a clear picture of what students might expect by the time they enrolled in a dental school. This conference also presented the potential that existed for developing a generic dental videodisc with as many as 54,000 dental images on it as a resource for dental professionals around the world. Following this meeting, the Northeast Regional Board of Dental Examiners developed a videodisc with more than 7,000 images on it as a demonstration project. Other projects using computers and videodiscs followed. The U.S. Navy developed a program to instruct corpsmen how to diagnose and treat 35 dental emergencies in order to address problems aboard naval vessels lacking a dental officer. In 1985 the University of Iowa introduced prototype interactive videodisc patient simulations in oral pathology and diagnosis.

Issues in Dental Informatics Education

The faculty are the key to implementation of dental informatics within dental schools. The faculty must be given the opportunity to increase their skills in basic instructional design, electronic instructional design, testing, teaching, and evaluation. Administrative commitment and involvement is critical to the adoption of dental informatics for faculty development as well as school-wide implementation. The administration should identify resources for faculty development, computer labs, and software development. Another critical issue that needs to be addressed by administration and faculty is evaluation and peer review of faculty research and publication in the area of dental informatics and its acceptance in the promotion and tenure process.

The goal for students is to excel in their dental education programs as they apply problem solving techniques in a high tech, high touch environment of supportive professional and peer review. The student must be sensitized to the professional beliefs and educational practices that will accompany entry into the profession under the new practice paradigm. Changes must be made in the dental curriculum, particularly in the area of summary evaluation. These changes must also be extended to the national, regional, and state licensure examination processes.

The nation's dental education institutions must participate in the development of a new paradigm for dental education which is based in dental informatics and focused on the linkages between problems and knowledge and the equivalence to the operational and educational settings. Information and communications standards also need to be addressed. This effort should take place in conjunction with the dental research and practice communities. At the very minimum, the learning environment should be:

- Problem oriented
- Interactive
- Self-directed
- Life-long
- Computer mediated.

To actualize this informatics based educational paradigm, changes must occur in the working relationships on informatics-related projects among associations and institutions. The collaborations among schools could take the form of nationally networked knowledge bases, linkages, aggregate data analysis, and other practitioner support systems as well as standardization of codes and database elements. A network of interested schools and institutions could share ideas, resources, products, and evaluation processes and outcomes.

Workshop Group Recommendations

To stimulate and encourage research activities in dental informatics the following should be accomplished by the dental education sector of the profession:

1. Encourage the development of strategic plans for the pursuit of dental informatics within each dental school, as well as within other associations and agencies.

2. Create a dental informatics consortium that would be comprised of all major associations, agencies, and related corporations which as a unit would:

   - identify the resources and expertise needed to pursue its goals
   - identify and solicit external funds
   - develop and submit grant proposals to federal agencies and philanthropic institutions
   - solicit, review, and fund informatics proposals which support the goals of the consortium
   - identify centers of excellence which will play leading roles in developing and diffusing appropriate standards and/or products related to dental informatics

3. Develop a major communications network among all key individuals, institutions, associations, and agencies.

4. Develop continuing education programs which would train current practitioners in applying dental informatics in the practice setting.

5. Initiate faculty development efforts in dental informatics appropriately tied to programs which teach improved skills in instructional design and general scholarship.

6. Work toward revision of promotion and tenure guidelines to adequately reflect the contribution of those faculty involved in the successful application of information technology to their teaching and/or scholarly efforts.

7. Encourage student use of computers, other hardware, and related media to integrate informatics tools into the instructional process and to replace memory-based learning and testing strategies with those that are problem-based.

3- Research in Informatics/Informatics in Research

The research workshop group posited several basic assumptions about dental informatics research. First, dentistry is an essential component of health care and dental informatics is a component of health informatics. Dental informatics research should contribute to the general field. Second, existing tools from medical informatics can and should be used in dental informatics wherever applicable. Third, the main task of dental informatics research should be to address the needs and issues of dental practice and education. Fourth, research in dental informatics should meet the required standards regarding validity and reliability, and should be hypothesis generated.

State-of-the-Art: Dental Informatics Research

Dental informatics can be viewed as consisting of two major areas:

- informatics in dental research and
- research in dental informatics.

The first area, informatics in dental research, refers to the use or inclusion of techniques from informatics in the methodology of research projects which are not focused primarily on a specific informatics topic. Thus informatics is applied to a clinical problem or laboratory investigation. The second area, research in dental informatics, is a new research area in dentistry and focuses on the design and building of tools or systems that can be applied to all areas of dentistry, e.g., research, education, practice, and administration.

Perhaps the best way to look at the myriad of dental informatics applications is to use Jan van Bemmel's model of involving the six levels of increasing complexity in medical informatics. This model brings some order to the wide variety of information systems which are arranged in increasing complexity with examples given within the parenthesis:

1. Input/output, communication (networking, data representation)

2. Storage, retrieval, databases (clinical or departmental information systems)

3. Computation, automation (laboratory automation, imaging, signal analysis, statistics)

4. Diagnosis, image processing, decision support systems, pattern recognition (expert systems, radiology systems)

5. Therapeutic support systems (automated prosthesis fabrication, radiation therapy)

6. Systems and methods for education, research, and development (simulation, modeling, new methods and systems).

As is true for most of the informatics research and experimental development, current research activities are at the highest levels and the applications developments in common everyday use are in the first three levels: input/output, communications, storage/retrieval, and computation and automation.

The first level, communication systems, input/output of data, is composed of several different areas. One such application is local and national conferencing. The University of Michigan Schools of Dentistry and Public Health have implemented a conferencing system, "ConferII," that is accessed from different areas across the country and is used extensively in Michigan. The American Association of Dental Schools is currently investigating the feasibility of linking together U.S. dental schools using one of the national networks such as Bitnet. The Canadian dental schools already link their schools using Netnorth, the Canadian counterpart of Bitnet. Another system in level one with which many schools are struggling is networking/data communications, local area networks, etc. Networking is not a new issue, but there has been no forum for exchange of ideas within the dental community.

The next area of increasing complexity is data storage/retrieval, databases, i.e., any system that collects and stores information. Dental schools have been struggling with the question of how to maintain their clinical information systems, a complex network of informational needs similar to a hospital information system. There are at least 40 schools that have institutional systems of some type which manage student grades and patient administrative information. Likewise, there are over 300 private practice office systems, but with one-third of these being replaced every year.

A specific example of a level two application is the clinical software development program at the University of Texas Dental School in San Antonio. This system contains a comprehensive health history questionnaire with 56 branching items; a drug information base of over 400 commonly used drugs that specifically relate to dentistry; an interactive computerized patient charting program called AutoChart that allows the dentist to chart simple or complex caries, restorations, and also periodontal disease. The system is written in C language in an attempt to facilitate dissemination of the system or sub-programs to other schools.

Many schools have embarked on similar projects with varying degrees of success, but how is all of this information integrated into one system? There is no mechanism for sharing these clinical data among schools and therefore many exciting research opportunities are lost. In an attempt to address this widespread problem, AADS and ASTM have formed a joint committee to establish standards for dental computing and informatics.

The third application level is computation and automation such as laboratory computing, image and signal analysis, and statistics. There are many different applications in this area, but a particularly interesting application blends the disciplines of informatics and dentistry.

Decision support systems, pattern recognition, and image processing are very important to dentists as they are by nature and training strongly reliant on the visual sense. These are examples of fourth level systems. A system developed at the Medical College of Virginia School of Dentistry is adapted from Weed's Problem-Knowledge Coupler system. This expert system constructs a database for problems containing possible causes and findings and comments on them and on the patient management options that a dentist may use. Similar types of systems are in development at the University of Medicine and Dentistry of New Jersey, while the School of Public Health at Columbia University has developed expert systems for enhanced work stations for dentists. The recurring problem, however, is that there are no standards for these decision support systems and no mechanism for sharing information about their development and implementation.

Fifth level applications, e.g. therapeutic support systems, therapy, and control, can be exemplified by some unique automated prosthesis fabrication systems developed by a French/Swiss team and one at the University of Minnesota supported by the National Institute of Dental Research. Preparation of the tooth for a crown is performed by the dentist and then a digitized image is made of this tooth preparation. From this digital image a computer-aided manufacturing system fabricates a crown out of metal or porcelain. With this system no impressions of the tooth preparation are necessary, while great accuracy of the crown in all dimensions is maintained.

The sixth level contains research applications and development in educational systems. The interactive videodisc simulations are classified in this level as is research in new methods of simulation and modeling.

Issues in Dental Informatics Research

Most information systems developed thus far are designed to address a specific problem or need and do not interact, or their design does not take into account the possible future need to exchange information with other systems. Systems should be developed that will facilitate efficient interactions between people and technology in the transfer of information. This includes the application of principles from ergonomics and artificial intelligence to the acquisition, processing, and output of data in dental research, education, and practice. Dental research should make use of informatics systems in data collection, design and construction of electronic and electromechanical instrumentation, including microcomputers, and the establishment and provision of access to a myriad of databases, e.g. bibliographic databases, clinical and epidemiological databases, patient registries, etc.

Expanding of Dental Diagnostic Systems

Although much research has been conducted into the use of causal models and causal knowledge for diagnostic reasoning and the construction of expert systems related to non-oral diseases, there have been relatively few efforts to develop similar types of systems for dental diseases. Future research needs to be conducted in the development and testing of computer-assisted diagnostic approaches for oral and facial disorders, for example, by comparing rule-based expert systems, Bayesian expert systems, neural networks, and human assessment. Other applications of informatics to oral diagnosis include developing and evaluating computerized radiographic systems; developing methodology for conducting MRI and other biomedical imaging procedures for temporomandibular disorders; personal computer-based control systems for monitoring the movements of the human mandible; devising procedures for cephalometrically identifying and classifying craniofacial anomalies; and developing and evaluating image analysis in periodontics.

Application of Techniques to Dental Practice

Studies can be conducted to determine the effects of dental informatics on such topics as the efficiency of healthcare delivery and patient satisfaction. This could be accomplished through clinical trials and studies which examine changes in patients' attitudes and behavior as a result of dental informatics utilization, and investigations of cost effectiveness. Specific dental informatics techniques that could be tested include interactive videodiscs and computer-assisted design and manufacture of dental restorations. Another related area that could be studied is the diffusion of computer applications in dental settings. For example, determining the dentist's view of computers; identifying the utilization, acceptance, and impact of clinical computer systems in research, education, and practice; studying the awareness and use of such information sources as Medline; and determining which types of information available through computers are wanted by dentists.

The Utilization of Dental Informatics in Health Services Research

This involves establishing easily accessible databases that would assist in analyzing and forecasting trends in demographics, disorder prevalence, economic changes, consumption of services, etc., on a regional, national, and international basis. Also included in this area would be the development of a standardized patient record that could be employed by large practices and health centers, insurance companies, and dental schools for purposes of evaluation, analysis, and cost setting procedures.

Approaches for Representation of Dental Knowledge

The organization and relationship of information for use by dental researchers, educators, and practitioners needs systematic investigation. This includes such projects as the development of a dental informatics vocabulary patterned after that currently employed by the National Library of Medicine and the major medical informatics organizations and the development of an overall nosology which can serve as the standard classification system for dentistry. This vocabulary should be compatible with similar efforts in medical informatics.

Workshop Group Recommendations

To stimulate and encourage research activities in dental informatics the following should be accomplished:

1. Identify a cadre of individuals to conduct dental informatics research and to serve as reviewers on study sections of funding agencies.

2. Encourage formal training programs for specialists and researchers in dental informatics.

3. Develop mechanisms for communicating information regarding relevant announcements for the Federal government about available grants and contracts. This could include the preparation of guides for dental informatics research proposals and distribution to potential applicants.

4. Identify and develop additional funding sources in the Federal agencies (e.g., National Library of Medicine, National Institute of Dental Research, and National Center for Health Services Research), foundations, industry, and among venture capitalists.

5. Encourage interactions between academia and the private sector, and stimulate technology transfer from government to private sectors.

6. Identify market research aspects of dental informatics to encourage investment by the private sector. Identify what and where the demand is for dental informatics tools and technology.

Part 4-Conference Outcomes and General Recommendations

During the closing session of the conference it became evident that there were several recurring themes that ran through each discussion by the three workshop groups. They may be paraphrased as follows:

- The principal focus of dental informatics applications should be on dental practice where they can impact most directly on the delivery of oral health care.

- The profession needs to support and facilitate the process of planning for both the short and the long term. At a minimum, planning should take place at two levels: (1) each major dental organization should develop a strategic plan based upon its own mission and needs; (2) each of the plans should be integral to an overall plan for the entire profession.

- Mechanisms should be developed early to ensure communication and networking among the various components of dentistry including dental professional organizations, dental schools, the dental research community, Federal dental services, individual dental practitioners of general dentistry and the dental specialties, dental auxiliaries, the dental trades, other health professions, and appropriate members of the computer and telecommunications industry.

- There is a strong need for the various sectors of the dental profession to achieve agreement on the important issue of standards related to nomenclature, classification and coding of diseases, and the size and number of database fields. There should be consensus on the issue of compatibility of information systems so connectivity can be maximized.

In addition to these more generic themes, some process issues were identified as well. If dental informatics is to be fully and expeditiously integrated into the fabric of dentistry, practitioners, faculty, and students who are currently active in the field need to recognize the utility and benefits to be derived from information technologies as tools promoting improved efficiency and effectiveness in dentistry.

With respect to the planning theme described above, selected organizational structures and elements need to be developed. For example, the participants agreed that each of the dental organizations represented at the conference should formulate a process to plan dental informatics initiatives as they impact and influence the future. More important, it was suggested that such planning should be part of a larger, "umbrella" type plan done by a consortium of dental organizations to ensure that an overall plan for dental informatics is well coordinated and complementary to other sectors of the profession.

The success of this consortium will be directly dependent upon the resources made available to it by its members; and while funding is always essential, among the most important resource elements will be the human talent each component of the consortium will contribute to the consortium, and the commitment of the parent organization to the overall plan and its implementation.

Another process issue is that of timing. Throughout the two and one half days of the conference there was a perceptible concern by the participants that the profession should move deliberately but also expeditiously into plan development. One of the basic characteristics of the field of information science and technology is the rapidity with which it changes. This phenomenon is clearly and simply illustrated by the remarkable growth and refinement of microcomputers which in less than 10 years have increased power from 16K to 640K of RAM. The conference participants' admonition to the profession, simply put, is to move quickly so that "catch-up" relative to other health professions can be maximized. Dentistry must also capitalize on the experience of other health fields so as not to repeat obvious misdirection and error.

To assist these organizations and the proposed consortium in this task, the original conference goals are restated below. Each goal then is followed by a series of specific action steps which the conference participants recommend as follow-up to the Aspen Conference.

Goal 1 - Define the parameters of dental informatics across all levels of dental organizations and activities.

- Identify forums for reporting recent dental informatics activities in the periodic dental literature.
- Develop a Consortium for Dental Informatics which would be composed of representatives from all major associations, agencies, and relevant corporate interests which, as a unit, would: (1) develop cooperative policies for the field of dental informatics; (2) identify the resources and expertise

needed to pursue its goals; (3) identify and solicit external funds; (4) identify "Centers of Excellence" which will play leading roles in developing and diffusing, through institutional consortia, appropriate standards, products, and services related to dental informatics.

Goal 2 - Develop strategies that will foster optimal use of dental informatics resources.

- Develop a catalog of informatics resources and interests.

- Establish a nationwide electronic communications network for the dissemination of dental informatics news as well as conferencing to foster collaboration and compatibility of information systems.

Goal 3 - Identify specific areas of research and development in dental informatics where the various segments of the dental profession could concentrate their efforts.

- The ADA and AGD should address dental informatics technologies as applied to the practice of dentistry and work towards the development of standards for information systems.

- The NIDR and NLM should prepare and distribute a set of guidelines for dental informatics research proposals.

- Identify a cadre of individuals to serve as reviewers on study sections of funding agencies for dental informatics grant proposals.

- The AADS should develop and distribute dental informatics educational guidelines to be used in faculty development and dental education programs at all levels.

Goal 4 - Identify areas for cooperative ventures and projects between professional organizations, educational institutions, government, and industry.

- Identify individuals and groups to work with the existing efforts, e.g. AAMSI, ASTM, to establish standards in the following: patient records, database design, and data communications.

- Establish informatics training opportunities as joint collaborations between educational institutions, NLM, and other interested agencies.

- Earmark positions for dentists in NLM sponsored and funded informatics training programs.

- Establish a task force comprised of representatives from dental education, dental practice, dental manufacturers, Federal dental services, and dental insurers to address standards in the dental record and related database design consideration for practice information systems.

Goal 5 - Lay the foundation for a cooperative strategic plan for dental informatics for the entire dental profession, so that individual components of dentistry can coordinate and accommodate their informatics planning and activities with the overall plan for dentistry.

- Each dental organization's strategic plan should address those strategic issues that are reflected in its mission as areas of informatics for which it is responsible. The plans should contain a short-term action plan for the immediate five years, a mid-range plan for years 5 - 10, and a long-range strategic plan for years 10 - 20.

- The U.S. dental community should actively participate in international dental informatics and planning efforts.

It is important to note that four common threads can be identified as running throughout the action steps just described: communication, priorities, compatibility, and advocacy.

Communication: Dental school deans and faculty should make greater use of Bitnet and other networks. ADA, AGD, and the dental specialty associations should consider development of electronic communication networks for the rapid dissemination of data concerning patient care, infectious disease, and other vital information.

Priorities: Planning and implementation priorities should be set so that future developments in dental informatics can be targeted to areas that at present are the most relevant and therefore will have the widest application and use.

Compatibility: Assurance is needed that dental informatics developments, technologies, and ideas can be shared when appropriate. The cost of development (time, people, and money) is too high to have a product or service that can be used only in one place.

Advocacy: Funding for research and development in dental informatics products and services must be generated. In the public and private sectors, dentistry must document that informatics will maintain, improve, and assure the quality of patient care.

A New Dental Practice Paradigm

The three workshop groups thus dealt explicitly and implicitly with a new and changing approach to patient care in dental practice. In the group discussions it was clear that the focus of the dental profession for the next decade must be devoted to the changes in dental care which are anticipated for the next century. All agreed that the evidence of changing dental disease patterns is compelling; that medical care is more complex and is heavily reliant on informatics for many forms of clinical decision making; that the role of the dentist in the health care arena must change. Indeed, it is expected that a new dental practice paradigm will emerge; one which will embrace four distinct components of dental practice: (1) development and maintenance of electronic patient records; (2) full use of expert systems and artificial intelligence in diagnosis, treatment, and prevention of oral disease; (3) computer management of fiscal and other practice administrative procedures; (4) improved communication between various professional elements based on electronic links.

Each one of the 150,000 practicing dentists in the United States makes an average of 12 new or incremental diagnostic and/or treatment decisions every day. These 1.8 million daily decisions are made using only human memory and an incomplete base of knowledge. A recent survey reported in the *Journal of the American Dental Association* revealed that 71 percent of the dentists surveyed were not fully aware of the recommended penicillin regimen for prevention of secondary bacterial endocarditis in patients with rheumatic heart damage. The survey also revealed that about one-third of dentists interviewed did not know that patients with a history of congenital heart disease are at risk for bacterial endocarditis resulting from dental procedures. Dental professionals can no longer expect human memory to function as the sole information manager for all of the data necessary for clinical decision making. A computerized decision support system integrated with a problem oriented record will give dentists the opportunity to overcome this problem.

These well established trends and rapidly emerging needs are already beginning to point to four guiding principles that will shape information management and systems design and function in the dental practice of the next century: (1) further evolution of effortless, accurate, natural language communications; (2) large, accessible, centrally-maintained databases; (3) continued development of efficient means for gathering, storage, and utilization of information; (4) evolution of natural, familiar, and invisible human-computer interfaces.

Thus dental practice in the twenty-first century will be conducted with the aid of a fully integrated information management system utilizing the most current computer technology. This system will be a sophisticated merger of business applications and patient record keeping. An additional element and key to its smooth functioning will be a nearly invisible decision support system that will function a level below where the user and the computer interact.

A patient reporting to the dentist's office will be directed to a computer station in the reception area that will take in all demographic data and obtain a medical and dental history and drug information using a human voice for input, thereby creating a permanent electronic record. From that point on, every time this patient interacts with anyone from the dental office, new information will be entered only one time. The decision support system will be functioning transparently to be sure the data go to every place they are needed. On a yearly basis, keyed to a central clock, the patient's age will be updated. When the age changes, or a new medication is added, or the patient is treated for a new disease or condition, the expert system will compare the new data with all information in the patient's file and to all relevant disease and management databases. In updating the patient's health status, the computer will recognize diseases, conditions, medications, and potential areas of drug interaction or disease history about which the dentist may need further information. The computer will then offer to search the National Library of Medicine on-line databases for the most current articles on the topic. An updated report on the health status of that patient will then be available for the dentist or other health professionals.

Such systems can function also as teaching tools in schools of dentistry. Students who learn using these information management systems would then naturally use them upon entering practice. Computerized decision support systems coupled with patient simulations will create a natural vehicle for continuing professional education.

Fiscal management will occupy less clerical time and more computer function in the dental practice of the twenty-first century. As names and codes for procedures become more standardized, simply updating the treatment record will generate the correct billing information for the patient. This information will be forwarded by electronic transfer directly to the insurance company or other reimbursement agency. In coming decades, more and more dental care will be paid for by sources other than the patient. Even today some types of practices already bill more than 80 percent of their accounts to insurance companies and other third parties. In the case where the patient pays the bill directly, the dentist's computer will automatically transfer funds from the patient's bank account to the dentist's account, eliminating the need for checks, charge cards, or direct billing. The electronic transfer of information will be bi-directional, with the dentist's records being updated when new information is entered into the patient's insurance records. Guided by invisibly functioning expert systems, changes in patient data such as disease states, disabilities, and classifications will flow freely from the central record storage facility to the patient chart, wherever that record may be, and office personnel will be freed from the tedious tasks of billing and filing claims.

One and one half million dentists world-wide, many practicing far from current sources of information, will welcome and greatly benefit from access to up-to-date knowledge bases to aid in daily decision making. With language translation and relatively minor modifications, these decision support systems and databases can be adapted to different styles of practice in other countries and cultures.

Other health practitioners also use large databases to find the causes to patient problems. Physicians, optometrists, podiatrists, nurse practitioners, clinical psychologists, and veterinarians could all benefit from using versions of computerized decision support systems, accompanying databases and continually updated patient record systems. The paradigms of information management are changing to make use of tools now available to aid in providing increasingly better levels of patient care.

Support for the new dental practice paradigm must come first through the leadership of national associations and agencies. It must then spread to practitioners, faculty, students, researchers, and patients. As the Aspen Conference on dental informatics reached adjournment, it was clear that the dental profession has developed and utilized a variety of technologic innovations directed at improving its ability to care for those it serves; it was clear also that the field of informatics has reached a point in its evolution where it will soon be fully integrated into dental practice, education, and research.

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Dr. Abbey began his work in informatics in 1984. His interest developed in the process of working with an expert system authoring program while constructing a computerized diagnosis and treatment system for use in dental practice. Since that time he has constructed seven diagnostic and/or treatment databases for various clinical problems dentists face every day. Additionally he has developed a Computerized Problem-Oriented Dental Record. Dr. Abbey is the former Director of Dental Informatics at the School of Dentistry, Medical College of Virginia/VCU, and is Software Editor of the Journal of Dental Education. In addition, Dr. Abbey is Chairman of the Working Committee on Curriculum Guidelines for Dental Informatics of the AADS, and a member of the AADS Committee on Information Technology. In May of 1989, Dr. Abbey gave an invited lecture at the International Symposium for Informatics in Medical Education; he has published a description of the system he has developed in the *Journal of Dental Education* and has presented his work at national and international meetings.

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Adelson's involvement in educational technology continued while Assistant Dean for Continuing Education at SUNY, and from 1977 to 1980 when he joined the Veterans Administration (VA) to become Coordinator of Medical and Dental Education at the VA's Northeast Regional Medical Education Center. His work centered around approaches for more cost-effective dissemination of information to practicing professionals, particularly those in sites far from academic centers. In 1980, Dr. Adelson moved to Washington, DC as VA Administrative Scholar and focused his two-year fellowship on technology transfer and practitioner competence. In his present role as Assistant Director of Dental Program Planning in the VA's Office of Dentistry, he has been involved in efforts to foster collaboration in the integration of dental services data and computerized learning systems.

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Dr. Donald A. B. Lindberg is the Director, National Library of Medicine. In addition to a career in pathology, Dr. Lindberg has made notable contributions to information and computer activities in medical diagnosis, artificial intelligence, and educational programs. He was recently elected President of the American Medical Informatics Association. He was Professor and Chairman, Director of Information Science, University of Missouri School of Library and Information Science, 1969-1971; Professor of Pathology, University of Missouri School of Medicine, 1969-1984; and Director, Information Science Group, University of Missouri School of Medicine, 1971-1984. Editor of medical journals and proceedings, Dr. Lindberg has served on several boards including the Computer Science and Engineering Board of the National Academy of Sciences, Symposium on Computer Applications in Medical Care (SCAMC), American Association for Medical Systems and Informatics, the National Board of Medical Examiners, and the National Academy of Sciences Institute of Medicine, and was chair of the U.S. Organizing Committee for MEDINFO 86. He is the author of four books, among them The Growth of Medical Information Systems in the United States, several book chapters, and more than 149 articles and reports. Dr. Lindberg is a graduate of Amherst College and received his M.D. degree from the College of Physicians and Surgeons, Columbia University.

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Dr. Lipton is responsible for coordinating all planning and evaluation activities for NIDR. The major planning activity at present is finalizing the NIDR "Long

Range Research Plan for the 1990s." In fulfilling his responsibility, Dr. Lipton employs several techniques and theories from the sociology of science, which attempts to understand research, science, and knowledge development within a social context. Evaluation activities in which Dr. Lipton is currently involved include the development of systems to examine, monitor, and assess the oral health research accomplishments of (1) extramural grantees funded by NIDR, as well as NIDR intramural staff working at NIH; (2) dental researchers supported by NIDR during training; and (3) dental institutions in countries throughout the world. For each component, Dr. Lipton is constructing databases which will be updated periodically to allow tracking of progress and performing longitudinal studies of the status of dental research. Present clinical research interests focus around the diagnosis and treatment of chronic facial pain, especially newer approaches that incorporate a biopsychosocial paradigm.

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Dr. Mumma has held appointments as professor and chair of the Department of Community Dentistry at Temple University and as Dean and Professor of Behavioral Sciences and Community Health at New York University College of Dentistry. He also served as a full time consultant in dental health for a six month period in 1975 at the World Health Organization headquarters in Geneva, Switzerland. He is a diplomate and former president of the American Board of Dental Public Health. His research interests are in the areas of dental epidemiology, health services research, and dental education.

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Dr. Errol L. Reese, a graduate of West Virginia University (1963) as well as the University of Detroit (1968), joined the faculty at the University of Maryland Dental School in 1968. After serving four years as a member of the faculty, he became the Associate Dean. Dr. Reese has served as Dean of the Dental School since September, 1974. Currently, he is serving as President of the American Association of Dental Schools and is active in international affairs within the profession of dentistry. At the request of the government of Taiwan, Dr. Reese has assessed the state of dental education in that country. He recently completed a six month sabbatical leave, during which he implemented a five year national program to recruit young men and women to the profession of dentistry.

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Dr. Salley, Professor of Oral Pathology at the Medical College of Virginia/VCU and Dean Emeritus at the University of Maryland at Baltimore, has served as Dean of the Dental School at the University of Maryland at Baltimore, Vice-President for Research and Graduate Studies at VCU, and Acting President and Vice-President of the Virginia Center for Innovative Technology. In the latter assignment, he worked with faculty from the research universities in Virginia in computer science, electrical engineering, systems engineering, biotechnology, and materials science and engineering. He assisted these faculty in forming partnerships with scientists in industry to promote technology development, transfer, and commercialization. He has been Science Advisor to two Governors of Virginia. Dr. Salley is interested in the integration of systems, case simulations, utilization of decision support technologies, and artificial intelligence, and their applications in dental practice. He is endeavoring to catalyze organization of individual academicians and practitioners so that integration and coordination of dental informatics efforts can be established, and so that the complete array of information technologies can be incorporated into all levels of health professions education and practice.

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Dr. Spohn graduated with a B.S. in zoology from Michigan State University in 1963 and entered the graduate program in genetics at Western Michigan University. He completed the D.D.S. program at the University of Michigan

School of Dentistry in 1969 and then entered a general practice residency program at the University of Kentucky. In 1970, he joined the U.K. Department of Restorative Dentistry as instructor. In the College of Allied Health, he held the positions of Chairman of the Department of Dental Hygiene and Assistant Dean. In the College of Dentistry, he presently holds the rank of professor and serves as the Director of Dental Auxiliary Programs. Dr. Spohn has served as project director for numerous grants and contracts for educational materials and program development. This includes an extensive project to develop four dental auxiliary curricula in Saudi Arabia. Dr. Spohn is currently a co-investigator on a Multimedia Interactive Teaching project in dental anatomy. He has co-authored one textbook and has contributed to several others.

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Dr. Suddick holds the positions of Professor, Department of Community Dentistry, and Professor, Department of Physiology at the University of Texas Health Science Center at San Antonio. While Dr. Suddick's long term career interests have been devoted largely to research in oral biology, in recent years he has devoted much effort to the emerging field of dental informatics. These efforts have been recognized at the UT Health Science Center by his appointment as Director of the Clinical Software Development Program (CSDP). The CSDP has been responsible for development of three dental clinical software programs. Dr. Suddick has been active at the national level in dental informatics. He is the founder and presently co-chair of the ASTM/AADS Joint Commission on Standards for Dental Computing and Informatics. He organized and was co-moderator of the Symposium entitled, "Computers and Dentistry: Role of the Dental Schools and the Need for Standardization." Dr. Suddick is a member of the AADS Committee on Information Technology. He has authored more than 80 articles and books, including several articles in the area of dental computing and informatics. He is principal investigator on the research contract: "Rapid Identification of Post-Mortem Remains by Computer: Interfacing Autochart and CAPMI Software Programs," which is funded by the U.S. Army Medical Research and Development Command, Ft. Detrick, Maryland.

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Dr. Weed attended Columbia University Medical School, graduating in 1947. He received training in internal medicine at Columbia, Johns Hopkins, Bellevue, and Western Reserve, and in biochemistry at the University of Pennsylvania; he became involved in basic biochemical research. He then assumed the role of Medical Director in the Eastern Maine General Hospital in Bangor, Maine where he worked out details of the problem-oriented medical record. Dr. Weed has been on the faculty of pharmacology and medicine at Yale. He was also Associate Professor of Microbiology at Western Reserve and Professor of Medicine at the same institution. He then went to the University of Vermont and developed the PROMIS Laboratory in the computerized system. Since the early 1980s, he has been developing the Problem-Knowledge Coupler, which is an outgrowth of the Problem-Oriented Systems.

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Dr. Wittenstrom received his D.D.S. degree in 1986 following which he became a Standards Division staff member at the Human Performance and Informatics Institute in Japan. He is currently the coordinator of HPI Institute's North American activities and is a part-time lecturer in the Oral Health Department at Tokyo Dental College. His activities as coordinator encompass the areas of standards, dental education, and dental practice. His specific projects in those areas are the continued development of a globally applicable health information management system based on a zero concept, health-oriented classification base; implementation of an educational program for dentists; and establishment of a network for practicing dentists who utilize the applications derived at HPI Institute.

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Dr. Zimmerman, a practicing dentist, is Director of Academic Computing and Health Informatics at the University of Maryland at Baltimore. He is responsible for using computers in the health care process, including practice management systems, computer based education, computer literacy, statistical computation, and user services. In addition to producing an audio tape for continuing education for the Academy of General Dentistry's Update Series entitled "Computers in Dentistry," Dr. Zimmerman also served as editor for the Dental Clinics of North

America's issue on "Computer Applications in Dentistry." In addition, Dr. Zimmerman has published numerous articles in informatics and computers in the curriculum and is on the Board for the American Association of Medical Systems and Informatics.

APPENDIX B

WORKSHOP GROUPS

INFORMATICS APPLICATIONS IN DENTAL PRACTICE
Louis M. Abbey, D.M.D., M.S., Workshop Leader

Richard Adelson, D.D.S.
Morris F. Collen, M.D.
Harold E. Donnell, Jr., B.S.
Robert F. Hill, M.S.E.E.
Anthony Lee Kiser, D.D.S., M.P.H.
Richard Suddick, D.D.S., Ph.D.
Lawrence Weed, M.D.

INFORMATICS AND DENTAL EDUCATION
John E. Eisner, D.D.S., Ph.D., Workshop Leader

Marion J. Ball, Ed.D.
Kenneth J. Cross, M.S.E.E.
Carolyn F. Gray, R.D.H., M.S.
Edward T. Herbold, D.M.D.
Lynn Johnson, B.S., M.S.
Errol Reese, D.D.S., M.S.
Eric E. Spohn, D.D.S.

RESEARCH IN INFORMATICS/INFORMATICS IN RESEARCH
James A. Lipton, D.D.S., M.Phil., Ph.D., Workshop Leader

Mark Diehl, D.D.S.
John A. Gray, Ph.D.
Larry C. Howington, M.S.
Donald A. B. Lindberg, M.D.
Richard D. Mumma, Jr., D.D.S., M.P.H.
John C. Wittenstrom, D.D.S.

APPENDIX C

KEY WORDS

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