What's New? Medical Informatics

Enrico Coiera
Intelligent Networked Computing Laboratory
HP Laboratories Bristol
HPL-94-24
March, 1994

Internet, world wide web, expert system, laboratory information system, electronic medical record

Invited contribution to the 'What's New?' column of the Australian Medical Journal, to appear April 1994.

1 Introduction

The last decade has seen a radical reappraisal of the role of the computer in medical practice. Previously it was common to find an emphasis on developing 'intelligent' computer systems that would assist clinicians arrive at diagnoses, or automatically generate treatment plans. Today, while there is strong evidence that such programs can be successfully manufactured, and many successful prototypes have been developed, there is a realisation that more pressing problems exist. Clinicians don't need immediate help with diagnosis and treatment selection - these are the tasks that they have been trained to do and they by and large do them well. What *are* urgently needed however, are computer systems which reduce the information burden of clinical practice - systems which allow rapid entry and retrieval of clinical notes, rapid order and reporting of investigations, and easy and timely access to the current literature [9].

As this shift in emphasis has occurred, the number of applications of computers in medicine has continued to grow. Many of these are hidden as computers become embedded within existing medical tools. It's unlikely that a patient monitor in ICU would be thought of as a computer, but that is exactly what it is. A modern monitor system may have more than a half million lines of program embedded within it to drive the processing and presentation of physiological signals onto the screen [4]. These advances are transforming such devices in the same way that computers transformed medical imaging - it was embedded computational power that changed the X-ray machine into the CT scanner.

What is not apparent to most practising clinicians is the breadth of information technology now available to them, and just how that technology can have real impact on daily clinical practice. While there is self-evident benefit in the use of the computer to manage the administrative side of clinical practice, and with signal processing tasks like imaging, many practitioners remain unconvinced of a more general role for such technology in the practice of medicine itself [10]. It would be fair to say that many of the expected clinical successes have failed to appear, but equally there have been several surprising success stories, not predictable a few years ago.

2 Global Information Access - From the Internet to the World Wide Web

The first surprise has been the way in which the marriage of communication technologies and the computer have changed the way information is shared and used. One of the outstanding success stories in recent years has been the growth of the Internet, a computer network linking thousands of smaller networks across the world, and counting it's users in the 10's of millions. Access to the internet is now basically available to anyone, even those who are not directly connected to the network but can connect a computer to a modem, and dial in to a subscription service.

The Internet allows free exchange of electronic mail amongst subscribers, and there are numerous informal specialist discussion groups that carrying out ongoing exchanges. Users can also access an enormous amount of information, which

- Alcoholism Research Data Base
- Australian National University Bioinformatics HypermediaService: Molecular Biology
- AIDS Information from the National Institute of Allergy and Infectious Disease
- CancerNet (NCI International Cancer Information Center)
- Clinical Alerts distributed by the National Institutes of Health and the National Library of Medicine
- Geneva University Hospital Molecular Biology Server
- Johns Hopkins Bioinformatics Web Server
- Molecular Biology WAIS Databases
- MEDLINE
- National Institute of Allergy and Infectious Disease
- National Institutes of Health (NIH)
- National Library of Medicine
- National Genetic Resources Program Gopher
- Online Mendelian Inheritance in Man
- World Health Organization

Table 1. A selection of services currently available on the Internet

include clinical databases and up-to-date literature (see Table 1). For example, the National Library of Medicine in the USA operates MEDLARS (MEDical Literature Analysis and Retrieval System), a computerized system of databases pertinent to biomedical research and patient care, accessible both by modem or the Internet, and includes MEDLINE, one of the world's most-used biomedical databases. The MEDLINE database contains article citations and abstracts, indexed from over 4000 journals in medicine and related health sciences.

One of the most interesting things about the Internet is the way it has been used in unexpected ways. For example, MEDLINE was set up initially as a tool for medical researchers, with the intent of allowing ready access to the latest published information. Quite unexpectedly, MEDLINE has been used by many practising clinicians to assist them in formulating diagnoses. Collecting together a set of symptoms and signs, these are entered as key words for the database search, and recent papers describing similar published cases are retrieved.

One of the limitations of Internet services had been that they were text based, limiting the type of information that could be sent electronically across the network. However, with the advent of the World Wide Web (WWW), a multimedia service available through the Internet, users now have access to not just text, but sound, images and video. For example, when accessing the University of Iowa College of Medicine's Virtual Hospital Service, users can browse through electronic textbooks, with pages containing text next to illustrative pieces of real-time imaging video or X-rays. The National Library of Medicine has also added a WWW resource to its existing services (Figure 1). Current NLM Web projects include the "On-Line Images from the History of Medicine" project through which over 60,000 photos and their catalogue information will be made available via the Internet.

(Figure 1 near here)

3 Expert Systems and Artificial Intelligence

Another surprise has been the change in the way we perceive the role of the computer in assisting the clinical decision process. After the first euphoria surrounding the promise of artificially intelligent diagnostic programmes [3], the last decade has seen increasing disillusion amongst many with the potential for such systems. *Expert systems* are the most common example of intelligent system, and typically collect together a set of rules obtained from human experts, and use these rules to automatically come up with conclusions based on clinical data from individual patients [1]. While there certainly have been ongoing challenges in developing such systems, they actually have proven their reliability and accuracy on repeated occasions [10]. Expert systems really do work.

The difficulty has been the poor way in which they have fitted into clinical practice, either solving problems that were not perceived to be an issue, or imposing changes in the way clinicians worked. What is now being realised is that when they fill an appropriately role, intelligent programmes can indeed offer significant benefits.

One of the most important tasks now facing expert systems developers is to accurately characterise those aspects of medical practice that are best suited to the introduction of artificial intelligence (AI) systems. To this end, over the last 12 months, the author has collected together a list of expert systems that are routinely used in clinical practice, by tapping into the global collected wisdom of the Artificial Intelligence in Medicine special interest group on the Internet. The list generated by the subscribers to this Internet group has at present about 25 systems on it, some of which are used at multiple institutions. For example, the PUFF system [11] for automatic interpretation of pulmonary function tests has been sold in its commercial form to hundreds of sites worldwide. Table 2 identifies the working systems currently on the list by category, and the full list can be obtained by subscribing to the AIM special interest group on the Internet.[1] The number of systems actually in use is no doubt far higher than this sampling shows.

What is clear from the list is that AI systems are actively working in many different roles, from patient education, through assisting clinical decision making, through to the management of health care delivery itself. The picture is very much different to that of a decade ago, when most systems were still experimental, and many

1. To subscribe to the AIM list, send email to ai-medicine-REQUEST@medmail.Stanford.EDU.

SYSTEM	DESCRIPTION
ACUTE CARE SYSTEMS	
ACORN	Chest pain triage advisor for CCU
POEMS	Post Operative care decision support
VIE-PNN	Parenteral nutrition planning for neonate ICU
LABORATORY SYSTEMS	
BECTON DICKINSON SYSTEMS	Haematology and MIC interpretation
GERMWATCHER	Analysis of nosocomial infections
HEPAXPERT I, II	Interprets tests for Hepatitis A and B
INTERPRETATION OF ACID-BASE DISORDERS	
LIPORAP	Phenotyping of dyslipoproteinemia
MICROBIOLOGY/PHARMACY	Monitors renal active antibiotic dosing
PEIRS	Chemical pathology expert system
PUFF	Interprets pulmonary function tests
EDUCATIONAL SYSTEMS	
CANCER, ME?	Personal advice on cancer risk reduction
DXPLAIN	Internal medicine expert system
ILIAD	Internal medicine expert system
QUALITY ASSURANCE AND ADMINISTRATION	
APACHE III	ICU outcomes prediction
COLORADO MEDICAID UTILIZATION REVIEW SYSTEM	Quality review of drug prescribing practices
MANAGED SECOND SURGICAL OPINION SYSTEM	Aetna Life and Casualty assesor system
MEDICAL IMAGING	
PERFEX	Interprets Cardiac SPECT data
PHOENIX	Selects most appropriate radiologic procedures
THALLIUM DIAGNOSTIC WORKSTATION	Diagnoses thallium myocardial scintigraphy

Table 2. Current list of working expert systems in medicine, grouped by application category. The full list with system details is obtainable by subscribing to the AIM special interest group via the Internet (ai-medicine-REQUEST@medmail.Stanford.EDU)

people bemoaned the fact that there had been very little movement of the technology into clinical practice. We should expect that the trend to introduce AI systems into clinical situations will continue, and indeed accelerate, over the next decade.

3.1 Expert Laboratory Information Systems

One of the most successful areas in which expert systems technology has applied is in the clinical laboratory. Practitioners may be unaware that while the printed report they receive from a laboratory was checked by a pathologist, the whole report may now have been generated by a computer system that has automatically interpreted the test results. In the same way that a computer is hidden from the user when we use a patient monitor, the computer system here is hidden behind the printed report. While simple automated interpretive systems have long been used to flag out of normal range values, the generation of diagnostic and therapeutic commentary by machine is still relatively rare in practice.

A successful example of this type of system is PEIRS (Pathology Expert Interpretative Reporting System), which currently runs in the Division of Chemical Pathology within the Institute of Laboratory Medicine at St. Vincent's Hospital, Sydney [5]. This is probably the largest single working laboratory expert system in the world to date, and is continually being expanded. PEIRS at present interprets about 80-100 reports a day, which is about 20% of all the reports generated by Chemical Pathology. PEIRS currently reports on thyroid function tests, arterial blood gases, urine and plasma catecholamines, hCG (human chorionic gonadotrophin) and AFP (alpha fetoprotein), glucose tolerance tests, cortisol, gastrin, cholinesterase phenotypes and parathyroid hormone related peptide (PTH-RP).

While PEIRS is an example of an expert system, emulating the diagnostic abilities of pathologist, it does not intrude into clinical practice. Rather, it is embedded within the process of care, and clinicians do not routinely need to interact with it. For the ordering clinician, PEIRS prints a report with a diagnostic hypothesis for consideration (Figure 2), but does not remove responsibility for information gathering, examination, assessment and treatment. For the pathologist, PEIRS cuts down the workload of generating reports, without removing the need to check and correct reports.

(Figure 2 near here)

In fact, about 3 reports a day are corrected by a pathologist, which gives the system a diagnostic accuracy of about 95% by this measure. A critically important and unique feature of PEIRS is that these corrections can be used immediately by the pathologist to correct the program's rule base, so that PEIRS continuously becomes more knowledgable about laboratory medicine. At the same time as the system becomes more accurate, it also becomes customised to reflect local conditions.

One of the hindrances to the general use of expert systems in medicine has been the complexity of the knowledge maintenance and enhancement task. Changing even a single interpretive rule can have subtle but far reaching implications for the accurate performance of an expert system. In years gone by it was assumed that it was necessary to have highly specialised computer scientists, called *knowledge engineers* to carry out knowledge base development and maintenance. The strategy successfully pioneered in the PEIRS system obviates the need for specialised engineers, and allows those who actually own the knowledge (i.e. the clinical experts) to maintain their own knowledge bases in a straightforward manner. At present the system has about 2068 rules that guide its interpretation of test results, which have taken about 150 hours of pathologist's time to build from scratch. The average daily burden for adding rules is about 15 minutes.

3.2 Machine Learning

The holy grail of AI is to develop computers that can learn from experience. Learning is seen to be the quintessential characteristic of an intelligent being. On the road to developing such systems, AI has developed a set of techniques in the field of *machine learning*, which offer the potential to alter the way in which we discover and represent medical knowledge. Learning techniques include neural networks, but encompass a large variety of other methods as well, each with their own particular characteristic benefits and difficulties.

All scientists are familiar with the statistical approach to data analysis. Given a particular hypothesis, statistical tests are applied to data to see if any relationships can be found between different parameters. Machine learning systems can go much further - they can look at raw data and hypothesise new relationships, and newer learning systems are able to come out with quite complex characterisations of that relationship. In other words they attempt to discover human understandable concepts.

Medicine has formed a rich test-bed for machine learning experiments in the past, allowing scientists to develop complex and powerful learning systems. The favour is now being returned, as these new technologies are now beginning to contribute to the corpus of medical knowledge.

Firstly, learning systems can be used as an adjunct to, or alternative for the development of knowledge bases used in expert systems. Given a set of clinical cases, along with their diagnoses, and the clinical signs, symptoms and test results, a learning system can produce a systematic description of those clinical features that uniquely characterise the clinical conditions. This knowledge can be expressed in the form of simple rules, or often as a decision tree. A classic example of this type of system is KARDIO, which was developed to interpret ECGs [1]. Clearly this approach can be extended to ill understood areas of medicine, and people now talk of data mining and knowledge discovery systems.

One particularly exciting development has been the use of learning systems to discover new drugs. The learning system is given examples of one or more drugs that weakly exhibit a particular activity, and based upon a description of the chemical structure of those compounds, the learning system suggests which of the chemical attributes are necessary for that pharmacological activity. Based upon the new characterisation of chemical structure produced by the learning system, drug designers can try to design a new compound that has those characteristics. Currently, drug designers synthesis a number of analogues of the drug they wish to improve upon, and experiment with these to determine which exhibits the desired activity. By boot-strapping the process using the machine learning approach, the development of new drugs can be speeded up, and the costs significantly reduced. At present statistical analyses of activity are used to assist with analogue development, and machine learning techniques have been shown to at least equal if not outperform them, as well as having the benefit of generating knowledge in a form that is more easily understood by chemists [7]. Since such learning experiments are still in their infancy, significant developments can be expected here in the next few y ears.

4 The Electronic Medical record

A third surprise has been how most people severely underestimated the complexity of introducing computer based patient records - a complexity in retrospect that reflects the complexity of the health care delivery system itself. At present many hospitals and medical practices do run their own local clinical information systems, capturing some aspects of the patient record electronically. They may also offer test and medication order-entry, and test result retrieval. However, there is a lack of uniformity between such systems, and exchange of information between the institutions that do have them is not easy. In fact, it is usually the case that individual hospitals have many different systems running for historical reasons, and it can prove to be an insurmountable task to even get these different systems to communicate with each other within a single hospital.

What is needed is a fresh start. It is becoming clear that a key aspect of information management is the rapid communication of information, and this needs to be tackled in parallel to setting up medical record systems. This trend is already in evidence in the UK, where the NHS is about to set up the Public Health Link as a precursor to a national NHS network in 1996, which will allow all NHS staff to communicate electronically. With well over 70% of general practitioners in the UK having computerised practices (a figure mirrored in other European countries like the Netherlands), it is clear that such a network is indeed feasible, and achievable in the near term. In the mean time, the Link system will allow rapid dissemination of urgent communications from the Department of Health to all practitioners in the country, within 6 hours if necessary, using computer network and paging technology [6]. It will also allow the speedy dissemination of public health information, and is built on the existing EPINET system, currently used by all NHS health authorities to exchange information on communicable diseases.

Equally as fundamental, is the realisation that electronic medical record systems need to share common standards to reap the benefits of information pooling, analysis and exchange. One of the biggest changes in health care delivery over the next decade will be the beginning of the process to uniformly computerise all clinical records at national and supranational levels. This is an explicit goal of many professional and government bodies not just in Australia, but around the world. For example the Institute of Medicine in the US sees the electronic medical record (EMR) as a key method for ensuring that the delivery of health care is both of uniformly high quality as well as ensuring that it is cost effective [8]. This is echoed in the Clinton government's health care plans [12]. As such, the development of uniform national standards for patient records, and national data "superhighways" to convey them between institutions are being actively pursued.

The patient record of the future is not now intended to simply replace the existing paper system, although the enforcement of minimum standards for data collection will be enormously beneficial. It is intended to be an integrated multimedia system, allowing the retrieval and display of images, text and real time video. Perhaps more fundamentally, the EMR will also enhance the scientific nature of medical care. The EMR offers the possibility of bringing the scientific discipline of clinical trials to the routine care of every patient. As more patient's are placed on protocols of care (a trend independent of the growing computerisation of medical records), and the outcome of these treatment episodes is captured electronically, the greater will be the pool of information available for large scale outcomes analysis. The newfound emphasis on communication between clinical sites will enhance the rapid and widespread dissemination of updated protocols defining standards of care.

5 Conclusion

It is a truism that without a measurement there is no way of deciding whether a change has been effective. With the advent of the EMR, and a more regulated approach to clinical treatment selection, the medical profession will have in its hands an enormously powerful tool that should not only help deal with the ongoing economic problems facing health care, but also improve quality of care, and contribute to the advancement of clinical science. Expert systems like PEIRS already sit in the background, adding an important safety net to clinical decision making, as well as being tools for improved productivity. With the recent development of information services like the World Wide Web, the movement of up to date clinical information around the world is now as easy as making a local telephone call.Developments in machine learning will allow the medical profession to not just sit on the mountain of information that it is now collecting, but to use this information to extract new medical knowledge. These changes are at the heart of current developments in medical informatics, and will ultimately have a profound effect on the shape of clinical practice.

References

[1]I. Bratko, I. Mozetic, N.Lavrac, *KARDIO: A study in Deep and Qualitative Knowledge for Expert Systems*, MIT Press, Cambridge Ma., 1989.

[2]B.G.Buchanan, R.G.Smith, Fundamentals of Expert Systems, in A. Barr, P.R.Cohen, E.A. Feigenbaum (eds.), *The Handbook of Artificial Intelligence*, Vol. IV, 149-192,Addison-Wesley, Reading MA, (1989).

[3]W.J. Clancey, E.H.Shortliffe (eds.), *Readings in Medical Artificial Intelligence - The First Decade*, Addison-Wesley, Reading MA, (1984)

[4]E. Coiera, Automated Signal Interpretation, in P. Hutton, Prys-Roberts (eds) *Monitoring in Anaesthesia and Intensive Care*, Bailliere Tindall Ltd., London, 1994, (to appear)

[5]Edwards G, Compton P, Malor R, Srinivasan A, Lazarus L. PEIRS: a pathologist maintained expert system for the interpretation of chemical pathology reports. Pathology 1993;25:27-34

[6]From the Chief Medical Officer, *Communications with the Profession*, PL/CMO (94) 3, UK Department of Health, 22 February, 1994.

[7]R. D. King, S. Muggleton, R. A. Lewis, M.J.E. Sternberg, Drug design by machine learning: the use of inductiove logic programming to model the structure-activity relationship of trimethoprim analogues binding to dihydrofolate reductase, *Proc. Nat. Acad. Sci., USA*, 89, 11322-11326.

[8]Institute of Medicine, *The Computer-Based Patient Record - An Essential Technology for Health Care*, Dick, R.S, Steen E.B (eds),Committee on Improving the Patient Record, Division of Health Care Services, National Academy Press, Washington D.C., 1991.

[9]E. H. Shortliffe, L.E. Perreault, G. Wiederhold, L. M. Fagan, *Medical informatics: Computer applications in health care*, Addison-Wesley, Reading, MA, 1990.

[10]Shortliffe E. H.,*Computer Programs to Support Clinical Decision Making*, *JAMA*, 258, (1987), 61-66.

[11]Snow, M.G., Fallat, R.J., Tyler, W.R., Hsu, S.P., "Pulmonary Consult: Concept to Application of an Expert System", Journal of Clinical Engineering 13:3, pp. 201- 205, 1988.

[12] *The President's Health Security Plan*, Times Books, Random House, New York, 1993.

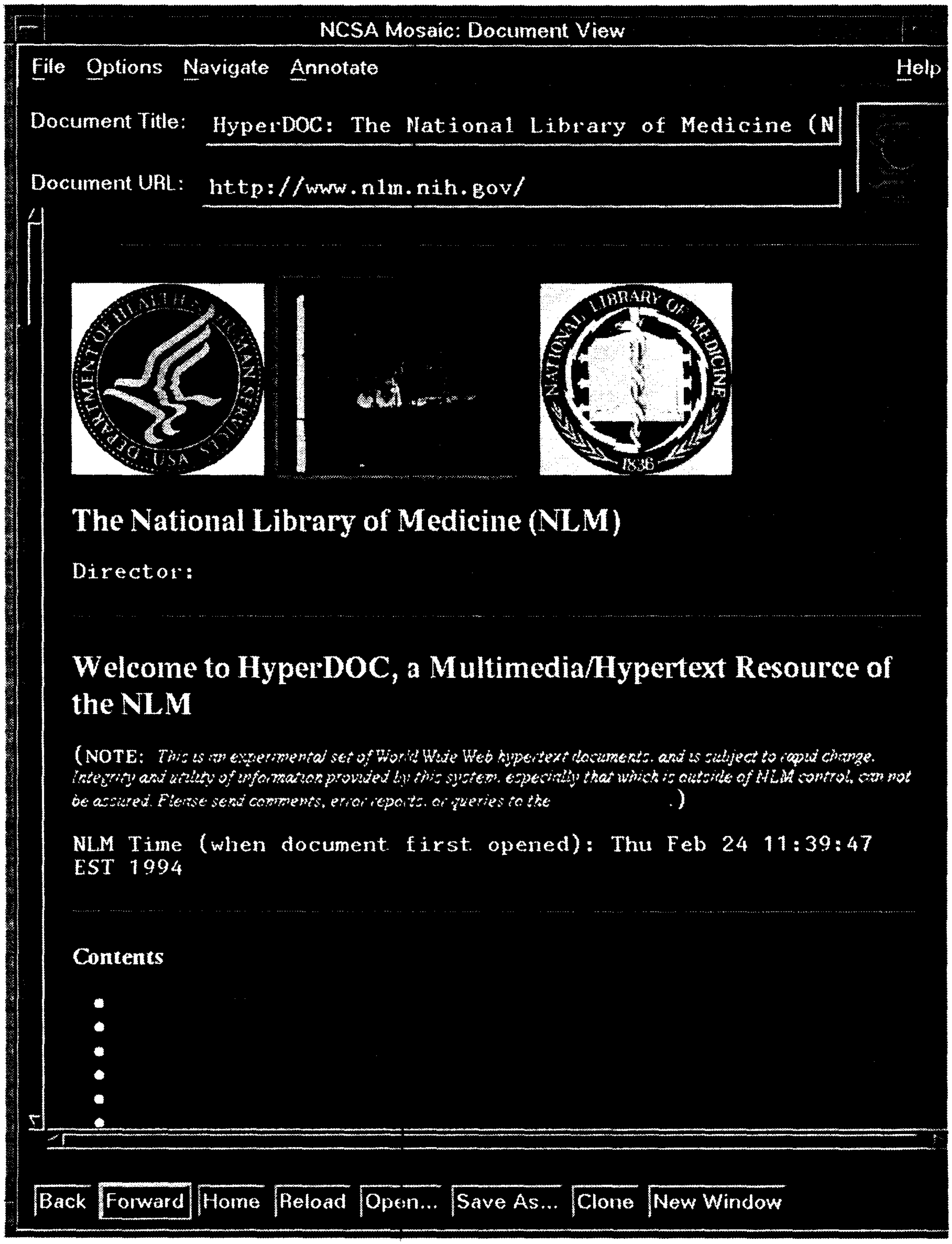
Figure Captions

Figure 1

A page from the National Library of Medicine's WWW service. Sections of the page act as links to other pages in the Web, which may either be on the NLM's service, or on another service across the globe. Sselecting a highlighted piece of text or an image will call up the page that it is linked to. The Web service makes browsing information extremely easy and one can typically access information from servers in many different countries in a single session on the Web.

Figure 2

A laboratory report generated automatically by the PEIRS system includes a computer generated interpretation as well as suggestions for further action.


NCSA Mosaic: Document View
File Options Navigate Annotate Help
Document Title: HyperDOC: The National Library of Medicine (N
Document URL: http://www.nlm.nih.gov/
The National Library of Medicine (NLM)
Director:
Welcome to HyperDOC, a Multimedia/Hypertext Resource of the NLM
(NOTE: This is an experimental set of World Wide Web hypertext documents, and is subject to rapid change. Integrity and utility of information provided by this system, especially that which is outside of NLM control, can not be assured. Please send comments, error reports, or queries to the .)
NLM Time (when document first opened): Thu Feb 24 11:39:47 EST 1994
Contents
Back Forward Home Reload Open... Save As... Clone New Window

St. Vincent's Hospital, Sydney

INSTITUTE OF LABORATORY MEDICINE

CHEMICAL PATHOLOGY REPORT

Patient .... : CITIZEN, JANE
Sex.............: Female
Date of birth...: 21.03.62

Specimen Source : ROYAL HOSPITAL FOR WOMEN
M.R.N. .... : 22-33-44

Test	Range	Units	BLOOD 08:30 06 May 1993	BLOOD 10:30 06 May 1993
Dynamic Test	... ...		GTT75	GTT75
Sample Time	... ...	minutes	0	120
Glucose	... ...	mmol/L	6.6	9.4

Glucose Tolerance Test: Glucose 75g given orally at time 0.

INTERPRETATION OF GLUCOSE TOLERANCE TEST:
Fasting glucose >5.5 mmol/L and 2 hr glucose >8.0 mmol/L consistent with gestational diabetes.
Suggest:
Clinical review.
Repeat 75g glucose tolerance test 6 - 8 weeks post-partum.