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Web-based results reporting and order entry

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Web-based Results
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Introduction

Computer-based ordering of clinical services has long been recognized as a potentially valuable tool for reducing health care costs and improving the quality of medical care. Significant financial and operational benefits can be obtained with a computer order entry and results reporting system that does not interfere with the simple process by which physicians write orders in the medical chart. Significant cost savings and clinical benefits can be obtained with a World Wide Web (Web) enabled order entry and result reporting system that replaces the multiple paper requisitions used by nursing and clerical staff to process physician chart orders for diagnostic clinical services. See Appendix A for a diagram of the workflow for laboratory order entry. Although additional substantial benefits can be obtained by direct physician order entry (see Table A), there are significant barriers to overcome that would require resources that are not currently at my disposal. These barriers, described by Massaro, Sittig and Stead (Massaro, 1993a; Massaro, 1993b; Sittig & Stead, 1994), are summarized in Table D and detailed in the Significance section.

This manuscript describes the development of a Web-based order entry and results reporting system. There are two major developmental goals. The first goal is to design a secure Web-based order entry and results reporting system ("WebOE") that complies with existing regulations, and enables the rapid, easy, and secure ordering of clinical laboratory tests using a Web browser instead of paper requisitions. A relational database repository with a Web server front-end processes test requests from the remote browsers, and transfers those requests electronically to a widely used laboratory computer system (Sunquest). Instructions, along with bar code labels affixed to the specimen containers, are locally printed for each order via a printer attached to each browser client. Java is used with bar coding software to generate the printing instructions. The ordering of laboratory tests via remote browsers saves costs by eliminating paperwork and reducing the extra labor required to manually transfer orders from the conventional paper requisitions into the laboratory computer system. The WebOE system is discussed in detail in the System Architecture section.

The second major developmental goal is to evaluate system feasibility by evaluating qualitative and quantitative differences between the traditional paper based system and WebOE. Following appropriate end-user training, evaluations will be performed as summarized in Table F and detailed in the Study Design section. Further system refinements and expansion to cover additional diagnostic services will be based on the results.

This manuscript details the expected benefits of a Web-based order entry and results reporting system (WebOE), progresses to a discussion of the system architecture and system goals, and concludes with a discussion of the current state of development. This WebOE project is a work in progress, with continued enhancement and refinement occurring as permitted by resources and time. This manuscript details both the present development and study efforts, as well as the future development and study efforts, that can be used as a blueprint to realize the goal of an electronic order entry and results reporting system at the University of California, San Francisco (UCSF) and other institutions.

The results reporting module of WebOE is close to completion. Communication of patient results is established between the Sunquest laboratory information system and WebOE. The user interface is undergoing refinement and bug fixes. The order entry module is currently undergoing communications testing with the Sunquest laboratory information system. The Current State of Development section of this manuscript has a detailed discussion of the current status of the order entry and results reporting modules.

Significance

Sittig and Stead note that it has long been recognized that computer-based entry of physician orders has considerable potential to reduce health care costs and improve the quality of medical care (Sittig & Stead, 1994). Table A summarizes some of the many theoretical benefits of computer-based physician order entry. Sittig and Stead also note that despite the extensive theoretical benefits associated with computer order entry, remarkably few hospitals have attempted to install either commercially available or homegrown computer systems for physician order entry (Sittig & Stead, 1994) (see Table D). This situation continues despite the widespread and successful use of computer order entry systems in the business setting. Successful installations, such as the one that Massaro describes (Massaro, 1993a; Massaro, 1993b), are infrequent.

Barriers to the use of computer order entry in clinical settings

There are three main obstacles (summarized in Table D) that have limited the use of computer-based physician order entry systems, as discussed by Massaro, Sittig, Stead and Bates. See the "Diagnostic service order entry: Substantial benefits without social upheaval" subsection for a detailed discussion of these obstacles as they relate to the WebOE system.

Technical barriers. Most physician order entry systems have been based on complex or proprietary designs that are difficult to develop, maintain, and modify in response to specific local needs, changing end-user requirements, and end-user feedback.

Economic barriers. The costs of installing and using complex home-grown or proprietary systems are substantial (e.g., costs of creating or modifying the user display, of installing and maintaining numerous remote workstations, of training multiple end-users on the use of a specialized computer interface, etc.).

Sociologic, political, and logistical barriers. Sittig, Stead and Massaro note that attempts to make dramatic changes in established work patterns and practice routines invariably generate complex behavioral, personnel, and institutional political problems (Massaro, 1993a; Massaro, 1993b; Sittig & Stead, 1994).

It is important to recognize that even where considerable financial and technical resources have been brought to bear, the sociologic barriers have made it very difficult to implement the use of physician-based order entry systems. Massaro describes this difficulty in his summary of the University of Virginia installation experience (Massaro, 1993a; Massaro, 1993b). Attempts to completely substitute a computer-based physician order entry system for the traditional medical chart require a major transformation in the behavior of physicians, nurses, and other medical staff. One can infer by the institutional experience of Massaro, and Sittig and Stead's review of computer-based physician order entry, that getting physicians to embrace computer order entry has proven to be particularly difficult. Sittig, Stead and Bates note that in many, if not most computer-based physician order entry systems, the time required for physicians to generate orders significantly exceeds the time required to simply hand write orders in the medical chart (Bates, Boyle, & Teich, 1994; Sittig & Stead, 1994). Physicians are justifiably reluctant to use a system that is perceived as shifting time and effort from lower paid personnel to more highly compensated medical staff.

Massaro and Teich make the point that by mounting major educational, political, institutional, and logistical efforts, a medical center may succeed in installing physician operated order entry systems that replace the use of handwritten orders on the medical chart (Massaro, 1993a; Teich, Hurley, Beckley, & Aranow, 1992; Teich et al., 1993). However, these exceptional successes are few in numbers. One can infer that without major institutional support, installation of an electronic order entry system that utilized direct physician order entry would be unlikely to succeed. Additionally, the successes have largely occurred as a result of a local team of highly talented individuals who were personally passionate about the concept of computer-based physician order entry and who had to push constantly for changes in policies and behavior throughout all levels of the institution. The system that Massaro describes continues to be successful and widely used at the University of Virginia, which provides hope that surmounting the barriers to implementation can translate into long term utilization.

From a practical business perspective, a commercial vendor is unlikely to succeed if their product depends on the need for someone to launch enterprise-wide, committee-based efforts to dramatically transform physician and medical staff behavior. Even in the absence of all technical and economic obstacles, the sociologic barriers will continue to hamper the spread of physician driven order entry systems. Unless financial or institutional incentives are provided to physicians, they will remain reluctant to take time away from a patient encounter to perform what could be accomplished in less time with a traditional paper form.

The benefits obtained from laboratory order entry are realized mainly in the laboratory, with increased efficiency, reduction of errors, and a great reduction in paper processing. One area where there are direct benefits to the physician is in pharmacy order entry. Assistance with formulary and insurance information, as well as dosage, allergy and drug interactions may provide enough incentive for physicians to perform electronic order entry. Indeed, various companies are now pursuing pharmacy and laboratory order entry on hand-held computing devices. One such company, ePhysician, is giving away 10,000 Palm™ handheld computers to selected healthcare professionals (ePhysician, 2000). By giving away the platform, the company hopes that the incentives provided by electronic pharmacy order entry will encourage physicians to use their services.

The WebOE for ordering diagnostic services: A practical approach to electronic order entry

Considerable financial and operational benefits can be obtained with a Web-enabled order entry and results reporting system that does not involve dramatic changes in medical staff behavior or disruption of the simple process by which physicians hand write orders in the chart. Specifically, significant cost savings and clinical benefits can be obtained with a Web-based order entry and results reporting system (WebOE) that enables nursing and clerical staff to efficiently process physician chart orders for diagnostic clinical services.

Commercial vendors already offer order entry and results reporting systems; however, the majority of these systems have not been Web-based and have involved complex, proprietary client server designs that are expensive to install, maintain, and modify according to varying local needs. Such systems cannot be readily customized by the diagnostic service providers themselves and because of their proprietary designs, they are difficult to integrate with the Web-enabled portable computer devices and the inexpensive network computers ("thin clients") that will increasingly be used in the future. Additionally, commercial systems solutions have so far been primarily monolithic systems. It is extremely difficult if not impossible to upgrade specific portions of these proprietary systems without upgrading the whole system. Additionally, legacy code is more difficult to maintain compared with code written using modern conventions (i.e. object oriented programming). This approach greatly increases the cost of making sequential improvements to the system, and greatly increases the maintenance costs. The current industry trend is to rely on a distributed architecture that allows specific components to be upgraded in a "plug and play" fashion. Thus, to capitalize on the networking revolution, an order entry and results reporting computer system for diagnostic service order entry that is fully Web-enabled would have a competitive advantage. This competitive advantage would result from lowering startup and maintenance costs to a level that is attainable by most hospitals and institutions. This is accomplished by utilizing a distributed architecture that facilitates incorporation of legacy systems, which precludes the necessity of purchasing expensive new equipment. Extensive investments of time and money by both commercial and non-profit entities have resulted in the creation of standards utilized by the World Wide Web and users of electronic healthcare transactions. A Web-based system can capitalize on this development to lower development costs and decrease time to market or time to implementation. Although few medical centers have yet to explore Web enabled client/server technology for their information systems, industry analysts consider this to be a prime area for growth during the next decade (Anonymous, 1997).

A Web-enabled computer system (WebOE) for diagnostic service (clinic or hospital ward) order entry and results reporting that can be implemented by clerks and nurses has clear potential to save on the substantial time and labor dedicated to processing paper orders for diagnostic clinical services (detailed in section below). Moreover, even with traditional diagnostic service order entry systems that are primarily used by nurses and clerks, it is possible to incorporate algorithms that facilitate adherence to clinical practice guidelines, as summarized by Finn (Finn, Valenstein, & Burke, 1988). A Web-enabled diagnostic service order entry system that can be driven by nursing and clerical staff will offer very attractive practical and financial benefits to medical centers that are searching for ways to cut operational costs.

Diagnostic service order entry: Substantial benefits without social upheaval

The benefits of Web-based diagnostic service order entry are summarized in Table E. To appreciate the substantial amount of labor that is saved by a computerized system for diagnostic service order entry, it is instructive to briefly review the sequence of events involved in a typical paper-based ordering system (see Appendix A). In most clinical settings, physicians first give written and/or oral requests to the nursing and clerical staff to obtain a multitude of diagnostic clinical services (e.g., laboratory tests, radiological examinations, pharmacy orders, social work consults, physical medicine and rehabilitation orders, respiratory care services, subspecialty consults, etc.). After receiving the orders, the nurse and or clerk locates the host of paper forms required to process the different diagnostic services requested. Assuming that all of the necessary forms are available, the nurse or clerk then fills out each form individually and determines if any additional information or material is required. In some cases, the nurse or clerk must locate another form or manual to find additional information that is required before the order can be submitted. For example, in the case of laboratory tests, it is sometimes necessary for the nurse to find and search a separate laboratory manual to determine the type of blood tube and specimen handling instructions needed to process a laboratory test. The nurse or clerk must then generate labels for the blood specimen tubes. Finally, once the paper requisition is sent to a diagnostic service unit, receiving clerks may then transfer the information from the paper requisition into the diagnostic unit's computer system. At UCSF, a 500-bed hospital with a full service Clinical Laboratory, four full FTEs are required to transfer requests from the paper requisitions into the laboratory computer system (Stephen Cohen, MD, Director of Clinical Labs, UCSF, personal communication). The use of a paper-based system not only requires extra steps in the ordering process, it can produce a bottleneck and delay in order processing when multiple requisitions from throughout the medical center converge on a central processing area. In addition, multiple manual transcriptions introduce potential areas for errors to occur (see Appendix A). The staffing and laboratory workflow of the Clinical Laboratories at UCSF is essentially identical to any similar hospital in the United States with manual laboratory order entry (Stephen Cohen, MD, personal communication). Thus, although the WebOE system is tailored for use at UCSF, adherence to clinical standards and readily available industry standard hardware and software (see System Architecture) ensures that the WebOE system can be generalized for use at other hospitals and institutions.

Labor savings. A properly designed Web-based diagnostic service order entry system will decrease the time spent by clerks and nursing staff to order multiple diagnostic services as well as virtually eliminate the additional clerks used by diagnostic services to transfer the paper-based requests into their local computer systems. For example, the elimination of clerical FTEs at UCSF's laboratory specimen processing area alone would allow for a very rapid return of investment in a moderately priced computer system (4 FTEs @ $45,000 per year in salary and benefits = $180,000 savings per year). How can a computer-based system decrease the time required for nurses and clerks to order diagnostic services? This can be accomplished by using a standard browser interface. Features of a browser interface that would facilitate this process are listed in Table B.

Increased Revenue. In an attempt to reduce what is seen as unnecessary laboratory testing performed on Medicare and Medicaid patients, the Health Care Financing Administration (HCFA) instituted Local Medical Review Policies (LMRP) affecting the ordering of laboratory tests. Physicians are required to provide a valid International Classification of Diseases 9 (ICD-9) diagnostic code for ordering laboratory testing on Medicare and Medicaid patients. Additionally, physicians are required to provide ICD-9 diagnostic codes from a previously defined and distributed list that "support medical necessity" when ordering specific laboratory tests that have been targeted by HCFA. For example, the ICD-9-CM diagnostic codes that support medical necessity for the laboratory test "Partial Thromboplastin Time", which is used to assess certain complex factors in the intrinsic coagulation pathway, are listed in Table C (Anonymous, 1998b).

Although currently these LMRP lists are defined regionally, there is an effort by HCFA to promote the use of universal national LMRP's to reduce the regional variation that now exists. These regulations are not limited to federal reimbursement but have generally migrated to all payers.

Many institutions, including UCSF, do not have the information technology infrastructure to cope with these requirements to ensure compliance with LMRP rules. Thus, they may perform laboratory testing that is not reimbursed by Medicare due to inadequate documentation of "Medical Necessity": an ICD-9 code from the appropriate list is not submitted with the test requisition. This leads to a loss of potential revenue. Vendors of traditional monolithic laboratory information systems have been slow to update their systems to promote compliance with LMRP rules, for many of the reasons detailed previously. A Web-based diagnostic service order entry can add this functionality with relative ease, thus ensuring an increase in revenue for the institution, as well as ensuring adherence to HCFA policies. Indeed, a "Medicare Compliance Module" was developed prior to the development of the results reporting or order entry components, and was considered for enterprise wide deployment at the now de-merged UCSF-Stanford Healthcare.

Reduction of Error. Reduction of medical errors has recently become an important topic of concern to consumers, as well as providers, of health care. Reinerstein and Leape et. al. note that medication error is the most common cause of patient injury due to medical error (Leape et al., 1991; Reinertsen, 2000), and is justifiably the focus of efforts to prevent medical injury due to medical error. Rubenstein also notes that when all sources of error are added up the likelihood that a mishap will injure a patient in a hospital is at least 3% and probably much higher (Reinertsen, 2000). Clearly, this represents a serious public health problem. Although laboratory related errors are not as numerous, reduction of laboratory errors will reduce the total risk to the patient. Fortunately, in a study of a stat laboratory tests, Plebani and Carrraro observe that most of the laboratory mistakes (74%) did not affect patients' outcome (Plebani & Carraro, 1997). However, Plebani and Carraro note that 19% of laboratory mistakes were associated with further inappropriate investigations, resulting in an unjustifiable increase in costs (Plebani & Carraro, 1997). Plebani and Carraro also note that 6.4% of laboratory mistakes were associated with inappropriate care or inappropriate modification of therapy (Plebani & Carraro, 1997). This cascade of effect, whereby laboratory errors lead to further medical errors, has the potential in resulting in serious harm to patients. Therefore, reduction of laboratory errors should be a priority for the healthcare system, as well as reduction of medical errors in general.

The WebOE system will reduce errors by reducing manual transcription errors (see Appendix A). Additionally, as additional order entry services are added (Radiology, Pharmacy, etc.), elimination of multiple transcription forms will reduce transcription errors further. Further, by employing electronic order entry, I anticipate a reduction of lost orders, ambiguous orders, duplicate orders, and illegible orders. I also anticipate that by improving turnaround time for results due to increased efficiency afforded by electronic order entry, physicians will be able to more quickly respond to abnormal laboratory values, and be able to more quickly administer appropriate therapy. Looking to future enhancements, once electronic order entry is in widespread use, advanced decision analysis could be incorporated into the WebOE system to discover cases of attempts to order inappropriate laboratory testing, and alert the end-user to prevent this from occurring.

Minimal disruption of current work routines with diagnostic service order entry. Diagnostic service order entry does not involve altering physician behavior or making changes in use of the traditional medical chart. Moreover, the changes in behavior expected of clerks, nurses, and other medical staff are relatively minor. Indeed, nursing staffs appear particularly receptive to technological innovations that result in more productive workflow. In a survey conducted by Gardner and Lundsgaarde, the facilitation of laboratory test ordering is ranked by nurses as one of the most desirable features of a computer order entry system (Gardner & Lundsgaarde, 1994). Table E lists additional benefits from Web-based diagnostic service order entry.

Addressing the technical obstacles. Rapid advances in Web and Internet technology have revolutionized the ability to efficiently share and exchange information on computer networks. As emphasized by Connelly and colleagues, the major technical barriers that have plagued development of clinical order entry systems can largely be avoided by using a Web-based open systems architecture (Connelly, Willard, Hallgren, & Sielaff, 1996; Willard, Hallgren, Sielaff, & Connelly, 1995). For example, in contrast to use of custom developed client packages or proprietary applications, changes to Web displays can be quickly made without having to alter a dedicated client application or obtain expensive vendor programming support. Moreover, the spread of non-proprietary Web Internet technologies, Ethernet backbones and connections, the standard browser interface, and inexpensive network computers will continue to greatly decrease the costs associated with setting up a distributed information network. Accordingly, a Web-based approach can be used to avoid many of the key technical and economic barriers (see Table D) that have stymied previous attempts to develop clinical order entry systems.

A Web-based approach requires strict security measures to ensure patient privacy and confidentiality, due to the use of potentially open networks. Robust security is built in to the WebOE system, which complies with current regulations (see System Architecture: Security for further details).

Addressing the economic obstacles. Cost of ownership is defined as the aggregate expenditure an organization spends on a computer system, which includes hardware, software, and ongoing maintenance. Kurkowski and Molta show that the initial cost of hardware and software is only a fraction of the total cost of ownership (Anonymous, 1998c; Kurkowski, 1997; Molta, 1999). Ongoing day to day maintenance constitutes the lion's share of cost of ownership. The use of a Web-based strategy instead of a traditional client server system greatly reduces both the software and hardware expenses of developing an enterprise wide information system. For example, Connelly and colleagues report a 10-fold gain in programming productivity associated with the use of a Web-based approach compared to the traditional client server approach in developing a hospital clinical information system (Willard et al., 1995). In comparison to proprietary client-server applications, the ability to use inexpensive network computer devices (NCs), existing PCs, and a Web browser to access the network greatly reduces the costs to purchase, install, and maintain multiple remote site workstations. Comparison studies of total cost of ownership (purchase and maintenance) show at least 50% savings associated with using "thin clients" (network computing devices) vs. traditional "thick-clients" (Personal Computers) (Anonymous, 1998c; Kurkowski, 1997; Molta, 1999). Network computing devices, coupled with browser-based applications requires very little maintenance, resulting in cost savings: there is no need for elaborate application software installation and setup or complex operating system installation, set up and maintenance. Additional appreciative cost savings can be realized in software distribution and installation. PCs running proprietary application software require field engineers to install the software individually on each system. When software bugs are discovered and enhancements or a fix is developed to remedy the problem, a field engineer is required to configure each system. These labor-intensive operations are expensive, time consuming and do not allow the rapid application of software improvements and fixes when necessary. In contrast, Web-based applications do not require manual client reconfiguration when enhancements are made to the application software. In Web-based applications, the software is downloaded to the client in the form of Java applets or HTML (Hypertext Markup Language - the language for describing Web documents) forms. Software enhancement can be performed in one central location only: the Web server. Substituting automatic propagation of bug fixes and updates for manual labor intensive procedure can lead to significant cost savings.

Moreover, as the standard browser interface becomes more and more widely distributed, the costs of training staff in the use of a Web-based diagnostic service order entry system will be much less than the costs of training staff to use the specialized interfaces associated with traditional client server systems. The use of a distributed architecture versus a monolithic architecture lowers both startup and maintenance costs. The ability to incorporate legacy systems preserves investment in existing systems.

While order entry proprietary systems are numerous, Web-based diagnostic service order entry systems were virtually non-existent at the inception of my WebOE project, but have begun to appear. Companies such as Quest Diagnostics, Caresoft, and WebMD are developing Web-based applications for diagnostic service order entry (Wilson, 2000). Sunquest Information Systems, Inc., in parallel with this current project, was developing a Web-based interface for its Laboratory Information System, which did not come to fruition. Sunquest instead chose to partner with Axolotl Corp., which had developed a Web-based diagnostic service order entry system (Anonymous, 1999a). This proliferation of Web-based development in the area of laboratory order entry and laboratory result reporting in a short amount of time provides an indication of the growing interest in this field. Small startup companies, who understand the new emerging technologies and know how to best apply them, possess sizable advantages over providers of traditional, proprietary systems. As a result of large investments in their current products, providers of proprietary systems are slow to change or adapt to new technologies, often acquiring new technology from other companies. For example, Sunquest, despite initiating internal development, chose instead to partner with another company to provide a Web-based solution to its clients. To traditional providers, new technologies require not only the redevelopment and complete redesign of their existing products, but also require expensive and prolonged training for the development staff to familiarize them with the latest technology. It is interesting to note that the companies previously mentioned that are taking a Web-based approach are relatively new companies without a heavy investment in proprietary, legacy equipment.

The cost of health care is high and is rising. Health care organizations look for ways to reduce costs, which often leads to a reduction in services. Delivering solutions, which improve the quality of health care and at the same time reduce costs is most attractive to health care organizations. Information Technology is a major expense: a hospital such as UCSF may devote 5-6% of the total budget to Information Technology.

Summary

Computer-based systems that can be used by clerks, nurses, and other medical staff to order diagnostic clinical services can provide substantial operational and financial benefits. A Web-enabled diagnostic service order entry system offers a number of important advantages over traditional client server designs (see Table E) and will be of increasing commercial value as more and more health care organizations embrace Internet and Intranet solutions for information management. A Web-based system will facilitate the ordering of diagnostic clinical services, reduce labor costs, and accelerate the speed and accuracy of transmitting physician orders to the diagnostic clinical sections. It is important to emphasize that a Web enabled diagnostic service order entry system can be readily expanded to include, or be integrated with, other Web-based systems providing information on patient laboratory results, radiology results, pathology results, insurance coverage, clinic reports, etc. Thus, although computer-based diagnostic service order entry represents only one aspect of medical information management, the proposed Web solution (WebOE) can be readily tied into future Web-based systems that have modules covering other aspects of the health care delivery system.

System Architecture

The primary concept is to use a Web browser and Intranet technology to link end users (nurses, clerks, and physicians or other health care providers) to the legacy computer systems that support processing of orders by the diagnostic clinical services. The key goal is to refine a Web-enabled diagnostic service order entry system specifically for laboratory tests. Future enhancements include additional diagnostic services (radiology, pharmacy, respiratory care, and clinical consult services).

The system is developed employing advanced Web technologies and software development methodologies. A relational database repository with a Web server front-end, facilitates the processing of the requests from the remote browsers, and transfers those requests electronically to a widely used laboratory computer (Sunquest). Instructions, along with bar code labels to be affixed to the specimen container, are printed for each sample via a bar code printer attached to each browser client. Java is used with bar coding software to generate the printing instructions.

To facilitate efficient resource utilization and quick and successful project conclusion, Rapid Application Development methodologies coupled with repetitive feedback from a group of end-users (3 nurses, 3 clerks, and 3 physicians) are used throughout the development and design process. A common pitfall that software developers need to avoid is embarking on a full-fledged system development based solely on interviewing users and on a business analysis. To achieve high levels of end-user acceptance, it is vital to involve the users throughout the development cycle. It is not enough to define the business requirements: users must approve the system's functionality. Systems which are clumsy to use and difficult to navigate slow down the work process and are often a source of end-user dissatisfaction, most often leading to abandonment. To avoid these pitfalls, strategies for effective human-computer interaction along with continuous feedback from users are employed throughout the development cycle (Heckel, 1991; Schneiderman, 1987). End users provide feedback on the Web interface every week during the design process. Initially, conventional HTML (Hypertext Markup Language) and Perl (Practical Extraction and Report Language) is used as a rapid prototyping tool and a quick way to demonstrate proof of concept. Once system requirements are well defined and user acceptance is achieved, the HTML screens are converted to XML (Extensible Markup Language – a second generation language for describing Web documents) and Java and application logic and rules are added.

Major challenges in software life cycle development include ease of maintenance, system expandability, and portability. The use of object oriented development methodologies eliminate redundant code, promote reusable code, and lead to a highly expandable system with low maintenance costs (Booch, 1991). Java is an object oriented language that is well suited for the job (Cornell & Horstmann, 1997; Geary & McClellan, 1997). Java has been designed as a networking language from the outset, is robust and portable across a large array of hardware, and has become an industry standard for Web-based applications (Cornell & Horstmann, 1997; Geary & McClellan, 1997). Security is incorporated into the language and is continually refined. In addition, Perl is a language that is used for many Web-based CGI (Common Gateway Interface – technology that allows Web servers to utilize external programs to process user input) purposes. Perl has object oriented features, and has many publicly available modules that extend the language, including modules for interfacing with relational databases in a fashion that is speedy and portable across many databases (DBI) (Bunce, 2000).

A relational database management system provides the means for transaction concurrency, data storage, and retrieval through easy to use structured query language (SQL) (Anonymous, 1992; Date, 1989; Ullman, 1982). An Oracle relational database management system is used for this project. From a development perspective, however, it can be advantageous to provide plug-and-play for other relational database management systems as advancements in relational database management system technology, or economic considerations, may require a change of the underlying database. Java combined with JDBC (Java database access), as well as Perl combined with DBI, provide relational database management system cross vendor portability (Bunce, 2000; Cornell & Horstmann, 1997): the same JDBC or DBI code can be executed against an Oracle or a Sybase database (Cornell & Horstmann, 1997). Security is maintained by using the Java Protected Domains Security Model. The Java Development Kit JDK 1.1 (see Hardware and Software) includes a standard SQL database interface, and the JDBC API (application programming interface). The relational database management system repository is used to store and process clinical laboratory requests and information, patient information, end-user profiles, and application logic and rules. To meet the individual needs of a diverse group of users, the system dynamically determine what forms, screens, and rules to apply. Initially, a default test ordering screen is deployed, with later development of a core set of HTML-based template order forms which can be tailored to specialty areas, allowing end users to self-select the initial test ordering screen. For example, clerks working on the Cardiology service will be presented with a screen containing the most commonly ordered tests by this specialty, streamlining the ordering process. Protocol order sets for specific services will also be developed to facilitate single click ordering of commonly used panels of tests, as demonstrated by Connelly (Connelly et al., 1996). A 128-bit SSL (Secure Sockets Layer – technology that enables secure Web transactions) enabled Web server is used with the browsers communicating in secure mode. CGI scripts and Java applets use asymmetric encryption to ensure patient confidentiality. This architecture provides a flexible system that can be tailored to each user based on needs and job requirements. In turn this leads to ease-of-use and fast navigation, as users will not need to traverse through impertinent fields and screens.

Figure 1 depicts the system architecture. The distributed architecture separates the application server from the database server to gain the flexibility needed to meet future requirements. However for small installations including the current test system, both application and database servers reside on a single computer. The application server facilitates access to the relational database management system repository and functions as a gateway to the legacy hospital systems via HL7-based (Health Level 7 – the dominant clinical messaging standard) clinical messaging services (see section below). Application logic and rules are retrieved by the application server, which dynamically constructs the appropriate HTML forms based on user profile and passes them to the browser. Patient demographic information is stored in the relational database management system and linked to each end user profile, so that for repetitive ordering, patients are selected from a list presented to the end user. This system requires no paper form to accompany the specimen since all order instructions are downloaded electronically to the laboratory computer. The relational database management system stores test request information, providing a record for each transaction, which can be electronically searched. Once the relational database management system receives the final test request(s) and an acknowledgment containing an accession number has been received from the Sunquest laboratory computer, a confirmatory response is sent to the client browser, along with the information necessary to print the bar code label(s) (see section below).

Legacy system communication and bar-code printing

In many medical centers, including UCSF, user interaction with legacy computer systems (e.g., laboratory computers and patient demographic computers) is typically handled through a telnet session using a "dumb" terminal. In the WebOE system, electronic data transfer from the Web browser into the legacy systems obviates the need for the additional clerical personnel that manually transfer information from paper requisitions into the legacy computers. Direct communication between the database server and the legacy systems is theoretically possible, however, in many settings, the necessary technical information may not be available due to lack of cooperation from the legacy systems' administrators and/or poor documentation of the legacy systems' database schema. The current system architecture supports communication with the legacy systems through direct TCP/IP (Transmission Control Protocol/Internet Protocol - the communication standard for the Internet) connections utilizing Health Level 7 (HL7) based clinical messages. HL7 is an ANSI (American National Standards Institute) standard for clinical-based messaging communications (Quinn, 1997).

Patient Admission, Discharge, and Transfer (ADT) information is obtained from the UCSF information system (IDX) via continuous HL7 messages obtained through an interface engine (a dedicated system that relays HL7 message streams, allowing a single message stream to be delivered to multiple systems). The average weekday message load is approximately 33,000 individual HL7 messages, while the average weekend daily message load is approximately 8,000 individual messages. Sunquest laboratory results are not received from the interface engine, but are received via a TCP/IP link from the application server to Sunquest. The Sunquest interface performs filtering of data that is required by UCSF's Clinical Data Repository (STOR). In order to preserve this data, and due to other factors, the interface engine is bypassed in favor of a direct interface that supports the transmission of more detailed data. The Sunquest link is also composed of a continuous HL7 message stream. The average weekday daily Sunquest message load is approximately 34,000, and the average daily weekend message load is approximately 6,000. Separate application daemons (Unix applications that run in the background and perform various functions) manage the individual links to the message streams, as well as utilizing separate application daemons to manage the loading of the data into the relational database management system. This allows for processes to continue even if one part of the system crashes. It also allows for future separation of tasks to different servers for increased and parallel processing ability.

After a test requisition is entered via the Web browser, the application server sends the order information to the laboratory computer via an HL7 message, and generates the appropriate bar-code label information. This information is then forwarded to the Web browser for label printing. Java provides controlling of local resources on a Web browser client system through the Java native methods interface. A native method is a Java method whose implementation is written in another programming language such as C. Using the C language, a Java native method interface is developed to access the browser's local printer port for printing of the bar-code label. After the bar-code label has been printed, the user affixes the label to the specimen container, which is sent directly to the laboratory for analysis. Receipt of the specimen in the laboratory is verified by scanning the bar code label affixed to the specimen container. Based on the test codes printed on the label, laboratory staff ise able to route the specimen to the appropriate section of the Clinical Laboratory for analysis.

Security

The advent of the Internet era has ushered in the proliferation of Internet-Firewalls as a means of controlling security. However, a Firewall by itself is not a panacea for comprehensive system security (Cheswick & Bellovin, 1994). To achieve robust security, a multi layered security approach is utilized. This includes physical access; operating system (Unix) layer; database layer; application layer; network layer; and firewalls.

Physical access. The server is placed in a secure room with access restricted to authorized personnel.

Unix layer. To minimize the potential of hackers attacking the server, operating system services are limited to the minimum necessary to provide required functionality (Curry, 1992; Farrow, 1991; Garfinkel & Spafford, 1991). No user accounts will be created on the server. User access to the system is done exclusively through the application. Login for administration activity is restricted to console, and NFS (Network File System) and NIS (Network Information System) are disabled.

Database layer. Access to the database is password-protected and limited to provide no more than the necessary functionality. Database rules and schema level privileges provide additional security, and CGI and Java programs that access database information utilize asymmetric encryption.

Application layer. Browser access requires a password, and three consecutive failed logins results in a time out. Browser password encryption provides an added level of security. Users are required to adhere to secure password selection (Curry, 1992; Farrow, 1991; Garfinkel & Spafford, 1991). The encrypted passwords are stored in the database along with authorized user list and user profile. A 128-bit secure SSL enabled Web server (Apache with SSL) is utilized

Network layer. Restricted IP addressing prohibits unauthorized clients from connecting to the Web server.

Firewalls. A laboratory firewall protects the server from unauthorized local intruders (see figure 2) (Chapman & Zwicky, 1995; Cheswick & Bellovin, 1994).

Using this multi-tiered approach ensures secure transmission of confidential patient information. By confining access to the UCSF Intranet, and restricting access from the Internet, the system is protected from malicious outside hackers. Additional security is obtained by using a secure server, user passwords, and encryption of data. This is an improvement over many of the current proprietary systems, which do not utilize encryption of data that is transmitted over the network.

There is one existing regulation, and one pending regulation that apply to the WebOE system. The Health Care Financing Administration (HCFA) issued the HCFA Internet Security Policy (Anonymous, 1998a) in 1998 that sets requirement for the secure transmission of Medicare or Medicaid patient information over the Internet. In brief, HCFA requires encrypted communication with user authentication or identification. Acceptable encryption is satisfied by: Triple 56 bit DES (defined as 112 bit equivalent) for symmetric encryption; 1024 bit algorithms for asymmetric systems; and 160 bits for Elliptical Curve systems. WebOE utilizes 128 bit SSL (symmetric) encryption, which satisfies this requirement. Since firewall protection is used, technically patient data is not transmitted over the Internet, however, future outreach applications will require transmission across the Internet, and therefore ensuring compliance now will facilitate future expansion of the WebOE system.

In August 1996, President Clinton signed into law the Health Insurance Portability and Accountability Act (HIPAA). One part of this Act, referred to as Administrative Simplification (Anonymous, 2000a), is aimed at reducing administrative costs and burdens in the health care industry. It requires the Department of Health and

Human Services to adopt national uniform standards for the electronic transmission of certain health information. Compliance with these standards will be required for anyone participating in the electronic transmission of the specified health information. The proposed regulations are available via the Web (Anonymous, 1999b), as well as the tentative schedule for publication of the regulations (Anonymous, 2000c). I will follow the progress of these regulations and ensure that the WebOE system is in compliance when the final rules are published.

System Reliability and Disaster Recovery

Because power outages, disk failures, and network crashes have the potential to interrupt the WebOE system, the following preventive measures and backup plans are included in the system design. All equipment is connected to the medical center's emergency power supply lines that automatically deliver locally generated power in the event of a local power failure. To ensure system uptime while the medical center's emergency power activates, uninterruptible power supply units are used. Thus, the servers, clients, and network-routers are protected by uninterrupted power sources. The Solstice Disk Suite (see Hardware and Software) is used to provide disk mirroring. The uninterrupted power supply coupled with disk mirroring provides a very cost effective means to insure system reliability and increased system up time. A 4 mm tape drive and the Solstice Backup Suite are used to backup application software, database, and operating system files on a daily basis. Oracle archiving is used for additional protection against a disk failure. All backup tapes are stored in a secure location. A supply of paper-based forms (a paper backup kit) will be available at each nursing station for use in the event of a serious network outage or catastrophic system disaster.

Hardware and Software Requirements

The hardware and software resources that are required need to accommodate the workload associated with the simultaneous ordering of multiple diagnostic services in a large medical center. Specifically, the server and database system is designed to handle up to 65,000 diagnostic service transactions per day. This is sufficient capacity even for a relatively large medical center with inpatient occupancy of 500 beds (assuming an average of 5-10 diagnostic service events per patient per day) and outpatient facilities handling up to 5000 patients per day (assuming an average of 2 diagnostic service events per patient visit). The hardware and software in use (see Appendix B) is based on this workload estimate along with the recommendations for system sizing and capacity planning provided by the hardware vendor (Anonymous, 1994)

Study Design

Client Browser hardware

In the initial evaluation on the client end, I will test each of the following hardware: IBM network station (network computers) with 32 MB RAM (Random Access Memory); Pentium class PC with 64MB RAM, 6 GB disk, Windows 98; Power Macintosh computers with 64MB RAM, 6 GB disk, and Mac OS 9. All clients will be equipped with 10BaseT Ethernet. These systems have been chosen as they are representative of the client hardware anticipated to be typically used in most hospital and clinic environments in the near future.

Usability Studies

A group of end-users will be tested for their perceptions of the relative convenience, speed, reliability, and ease of use of the Web-based system versus the conventional paper-based system for ordering laboratory tests. This will be addressed by: 1) Administering a questionnaire to ward clerks, nursing staff, and other end-users after a two week trial period of the Web-based order entry system in a defined hospital ward setting and; 2) Comparing the number of Web-based laboratory orders to paper-based laboratory orders during a 4-week period in which both test-ordering systems are routinely available within the same clinical environment.

Based on the outcome of these studies, the system will be refined as necessary, and expanded to include multiple diagnostic services. The system will be tested in both hospital and clinic settings, as time and financing permit.

Pilot testing site

Once the development and testing is performed (of the prototype Web pages, CGI framework, and network-accessible, relational database system), a pilot of the system will be implemented on an inpatient ward of the Moffitt-Long Hospitals (the two hospitals are directly connected and function as a single entity). The pilot testing will be performed with the nursing and clerical staffs from the 12th floor of the Moffitt-Long Hospitals which includes medical patients, surgical patients, as well as research patients from the General Clinical Research Center. Note: the nursing and clerical staff chosen to participate in this pilot testing will be different from those chosen to provide advice on development of the Web interfaces. This location for pilot testing was chosen because it includes a mix of different patients and the nursing and clerical staffs are accustomed and receptive to participating in research protocols. The test system will include 6 Java-enabled browser workstations using a mix of hardware that is likely to be available at most medical centers either now or in the near future (2 PCs running Windows 98, 2 Macintosh PCs running Mac OS 9, and 2 network computers). This will provide a sufficient number of workstations so that users will have access to the system without waiting (daytime ward staffing on 12 Moffitt-Long typically includes 2 clerks, 4-6 nurses, and 4-6 patient care assistants).

The target group will first be given a brief 20 minute training session in which I will demonstrate the use of the Web browser to order a series of laboratory tests on 3 fictitious patients. Each staff member will then be observed while ordering a series of laboratory tests on an additional 3 fictitious patients. I will handwrite orders in 3 mock medical charts and request tests similar to those that might be ordered on an ICU patient, a general medical patient and a surgical patient with a postoperative bleeding problem. The staff (day shift) will then be asked to use the Web browser to order all laboratory tests during the ensuing 2 weeks. I will be present to observe how the staff uses the system and to note and assist with any problems encountered throughout this period. This information will be used to refine the system and modify the design as necessary. After the two-week testing period, a questionnaire will be administered to each of the end users (described below). The system will be modified to further improve ease of use and functionality to address any problems that the survey and questionnaire uncover. The objective is to arrive at a design that is perceived by the end users to be more convenient and faster to use compared with the conventional paper-based requisition system.

Questionnaire:

The questionnaire (see Appendix C) employs a 7 point answer scale with questions derived and modified from studies of Gardner et al. and Sittig and Stead in which nurse and clerical staff identify positive and negative aspects of other order entry systems (Gardner & Lundsgaarde, 1994; Sittig & Stead, 1994). Each participant will be asked to answer the same question for the Web-based ordering system and for the conventional paper-based ordering system. The questions relate to how easy it is to use each system, how easy it is to learn to operate each system, the amount of time required to place orders with each system, and the amount of time required to obtain results ordered with each system. In addition, a space for free text comments is provided that will allow subjects to make comments about any aspect of the Web-based ordering system.

Statistical analysis and interpretation of results:

The median response scores will be determined and the data analyzed by the non-parametric Wilcoxon signed-rank test using the SigmaStat software package; for each question, the answer scores that pertain to the Web-based system will be compared to the answer scores that pertain to the paper-based system. Statistical significance will be defined as $p < .05$ after the Bonferroni correction for multiple comparisons. Although sample size techniques are not routinely used in developing non-parametric study designs, the number of categories per question (7 per question) is sufficiently large so that for purposes of a power calculation, I have assumed a normal distribution of results. For a paired design in which $n=10$, the current study will have an approximate 80% power for detecting a 1 unit difference in score, assuming that the expected standard deviation of the differences will be 1 unit. I will target for improvement those areas in which the median score for the Web system is less than 4.0 or where the median score for the Web system is significantly lower than that of the paper-based system.

Evaluation testing and criteria for assessing feasibility:

Based on the results of the questionnaire and on the free text comments, additional feedback will be obtained by directly interviewing users about the specific areas where improvement is needed. Once the additional improvements have been implemented, I will carry out an evaluation test in which I compare the number of Web-based laboratory orders to paper-based laboratory orders originating from the 12th floor of the Moffitt-Long Hospitals. This will be accomplished by daily counts of the number of tests ordered on paper requisitions and the daily counts of the number of tests ordered via the Web from the 12th floor during a 4-week period (between 8am and 4pm). Test requests from staff not trained in the use of the Web-based system will not be included. The Mann Whitney U test will then be used to compare the median daily number of tests ordered on paper requisitions to the median daily number of tests ordered via the Web. I will consider that system feasibility has been demonstrated if the median daily number of tests ordered via the Web is similar to, or significantly greater than the median daily number of tests ordered via paper requisitions. It is possible that the number of tests ordered via the Web system will be significantly lower than the number ordered via paper requisitions. If this occurs, direct interviews of the ward staff will be conducted to determine why the Web system was not being used as expected. Further refinements will be performed as necessary, with repetition of the evaluation test. Successful demonstration of feasibility will lead to expansion of the system to cover additional support services including radiology and pharmacy. This additional functionality will be subjected to testing in both hospital and clinic settings.

Evaluation of the Web System

The system will be evaluated for accuracy of electronic ordering and specimen turnaround time to ensure system reliability. The turnaround time of the Web-based system will be compared to prior turnaround time figures and concurrent turnaround time figures for the paper-based system. Additionally, the turnaround time will be measured for the Web-based system and the paper-based system separately and concurrently, to ensure that similar measurements are obtained. This will be addressed by manual tracking of laboratory orders as they appear on the chart. A comparison to the orders that are entered into the Sunquest Laboratory Information System will be performed to document discordant test requests. Additionally, the "loss rate" (number of test orders that are entered into the Web-based system, but not recorded and run by the laboratory) will be determined and compared to the loss rate for the paper-based system. The time the order is written will be compared to the time that the laboratory test result is available. This will be performed for both the Web-based order system and the legacy paper-based system. During the initial 2 week and 4 week trial periods, all laboratory orders will be tracked and analyzed. As system deployment moves beyond the trial period, randomly selected laboratory orders will be tracked and analyzed. The assumption is that the accuracy of the Web-based system will match the accuracy of the paper-based system, and that due to a direct connection with the Sunquest Laboratory Information System, turnaround time will be improved in the Web-based system. However, the true cost savings are realized with decreased system cost and decreased personnel needs. If turnaround time is comparable between the Web-based and paper-based systems, the cost advantage is still present and compelling.

<u>Statistical analysis and interpretation of results:</u>

The mean turnaround time will be determined separately for the Web-based system and the legacy paper-based system, and compared to determine if there is a statistically significant difference. Additionally, the error rate between written orders and orders entered into the Sunquest Laboratory Information System will also be determined separately, and compared to determine if a statistically significant difference exists. Similarly, the loss rate, if present, will also be compared between the two systems. An unpaired two-tailed t-test will be performed using SigmaStat software and statistical significance will be defined as $p < 0.5$.

I suspect that certain levels of transcription errors are present, where handwritten orders are interpreted incorrectly. These errors will be present on both systems. Additionally, I suspect both systems will contain errors where the interpretation is correct, yet errors are introduced by checking an incorrect box. By examining the difference in error rate, I will examine what effect an electronic interface will have on the latter errors. If a greater error rate is encountered for the electronic form, then the individual errors will be analyzed. This will be used to determine what improvements to the interface will need to be made to try to correct for these types of perceptual errors, with the goal of minimizing these errors as compared to the paper-based system.

Current State of Development

Due to delays in obtaining the necessary data feeds (Admission, Discharge, Transfer information - ADT, and laboratory results), the WebOE project remains in continual development. However, the data feeds necessary for the project conclusion have been obtained, and development efforts can be focused on achieving the goals outlined in this manuscript. The results reporting component is nearing completion. The order entry component development is on hold while the results reporting component is finalized, however, initial communications testing has been completed on the order entry component.

The end user evaluation of the WebOE project awaits completion of the results reporting and order entry components. Thus far in the development cycle, the project hardware and software are capable of managing the data streams, loading the data in the Oracle relational database management system, and providing Web server functions. If performance begins to suffer, additional hardware can be purchased to offload processes to one or more servers.

Results Reporting

The main objective of the results reporting module is to provide a user interface that is familiar to the end users. Thus, the interface is modeled after the existing STOR interface. STOR is a proprietary, UCSF-developed clinical data repository that provides telnet-based access to a wide variety of resources and clinical data, including Laboratory, Pathology, Radiology, among others. The initial user screen is shown in Figure 3. It is a text-based system, as evidenced by the prompt at the bottom of the screen. There is no user customization possible; navigation occurs by entering text, based on a provided menu of options, or by entering patient-specific information.

As shown in Figure 4, to view laboratory results, "1" is entered, which produces a prompt for patient entry. It is notable that the only default prompt that is provided is the medical record number of the last patient queried (not shown in the figures). A useful feature of the system would be to allow physicians caring for hospitalized patients to enter their list of active patients, thus providing a simplified manner of accessing the results for these patients.

Results are displayed in tabular format, with additional options located at the bottom of the screen (see Figures 5 and 6). Choices for user customization of the display are not provided, nor are they available. Candidates for such choices are listed in Table G.

Such customizations would save physicians time, and alert them to information that was not previously available to them. A major inconvenience of listing results sorted by order date is that laboratory tests do not take a uniform amount of time to yield results. Some tests have a turn-around time in terms of several days, and it becomes tedious to search for prior tests to verify if there is a new result. Also, a common task for housestaff and attending physicians taking care of inpatients is to review each patient's laboratory values daily before rounds. An automated procedure to do this would be save a tremendous amount of time and effort. This flexibility can be built into Web-based results reporting systems very easily.

Figure 7 shows the current state of the WebOE results reporting component development. As can be seen with a comparison of Figures 5 and 6, this represents a user interface that is remarkably similar to the STOR interface. This provides a familiar environment for users, allowing them to acclimate to a new procedure for viewing laboratory information, and allows for incremental addition of functionality. Two interface enhancements are apparent. As seen in Figures 5 and 6, STOR flags results that are outside of the reference range ("Normal Range") with an asterisk. Although this serves to alert the user to potentially important information, a greater impact can be generated by the use of color. STOR is limited by the technology it employs: telnet-based session accessed from "dumb" terminals. A Web-based system suffers no such limitation. The addition of color highlighting allows easier identification of important information. The flagged tests that are outside of the reference range in the Web-based results reporting system are much easier to visualize due to highlighting the results in yellow. Although red is a more commonly used color to indicate danger or alert, up to 20% of the male population is red-green color-blind.

Another visual enhancement that can be seen is the addition of the "graphing" graphic to the left of some of the test names (laboratory tests that have a numerical result). STOR provides a way of "graphing" historical values for a particular laboratory test (a text based graph is generated), however, the system is cumbersome to use, and requires the user to remember the test code (ACRO header in Figures 5 and 6). It is a very useful feature, but one that is not widely used, at least among laboratory medicine residents (personal communication). The Web-based results reporting component reduces the process of looking at historical values to a single click: clicking on the "graphing" graphic produces the result shown in Figure 8.

In this example, the historical values for BUN (Blood Urea Nitrogen, a test that gives an indication of renal function), can be easily obtained. This usefulness cannot be underestimated. The ability to see trends in laboratory data, especially during therapeutic drug monitoring, can alert physicians to important diagnostic information that cannot be obtained by a point measurement, and can lead to improved patient outcomes (Uehling, 2000). Additionally, freely available graphics libraries, such as the ImageMagick (Anonymous, 2000b) and GD graphics libraries (Boutell, 2000), can be installed on Unix-based systems (as well as other operating systems), to provide the ability to display the historical values in a graphical format (Wallace, 1999). A freely available Perl module exists, PNGgraph (Bonds, 2000), that utilizes the GD graphics library. Using PNGgraph, the process of producing a line graph of values is reduced to less than 10 lines of Perl code. Thus, incorporating graphical output to the WebOE results reporting component is a relatively easy endeavor, and one of the first enhancements that will be performed.

Other enhancements, such as the ones mentioned earlier (sorting based on result date and time, etc), can and will be added to the WebOE results reporting component. Another enhancement relates to the display of microbiology results (not illustrated). Access to microbiology results in STOR requires access to a different function ("14" vs. "1" for general laboratory, see Figure 3), due to limitations in display of information. WebRR is able to integrate microbiology results and general laboratory results in a single continuous display.

Order Entry

Whereas electronic laboratory results reporting exists at UCSF, there is no corresponding electronic order entry. This is currently being investigated at UCSF through the IDX installation project; however, physician order entry is not targeted for the initial installation. The de-merger of the UCSF Stanford Healthcare organization has introduced delays in even the initial IDX installation (sans physician order entry), which has a target installation date of October 2000, but will assuredly face more delays. Thus, IDX-based physician order entry is still several months to several years away.

Appendix D shows the most recent UCSF Laboratory Order requisition form. Initial development of the WebOE order entry component, analogous to the results reporting component, seeks to emulate the appearance of the form to provide end-users with a familiar ordering process. Future enhancements and development will focus on streamlining the electronic order entry process in a gradual fashion to ensure a smooth transition for end-users.

Figure 9 shows a developmental user interface for the WebOE order entry component. Selection of a patient, where appropriate, such as in the inpatient setting, will occur via a drop-down selection box. The user is greeted by an electronic version of the information that is requested by the paper-based laboratory requisition. An added feature is a running list of the tests that are selected, with the Sunquest test code displayed along with the test name. Figures 10 through 13 show examples of the order screens for Hematology, Urine, Other Blood test, Other Body Fluids and CSF. Not pictured is a text box for entering free text for laboratory testing that is not listed in graphical form. Navigation between the various sections will be accomplished with navigation aids in the top frame, next to the patient selection box. Consultation with medical specialists (i.e. Pulmonary, Hematology, and Cardiology) will enable the creation of specialized order entry screens, for rapid order entry based on specialty practice. These could be further customized by end users, with the development of a user interface for creating customized order sets. This will be stored as a user preference in the Oracle database.

The communications aspect of the order entry component of the WebOE system is not as advanced as the results reporting component. Delays in installation of the Sunquest order entry module (required for HL7-based order entry) contributed to the slow development. Development on the order entry component was temporarily halted when the Sunquest results reporting interface was finally installed and tested. Development has focused on the results reporting component since the results reporting interface went "Live" on January 19, 2000. Web-based results reporting can provide functionality and benefit in the absence of order entry, but electronic order entry would be facilitated with electronic results reporting.

Nevertheless, initial communications testing was completed before development efforts focused on results reporting. Appendix E shows an example of a new order electronic request in HL7 format that was communicated to the test area of the Sunquest Laboratory Information System. A single HL7 message contains multiple message segments, which carry individual data units. Data units are separated by the pipe symbol

"|", and individual data units can be tokenized using the carat symbol "^". For example, Appendix E illustrates a single HL7 message with the following message segments: MSH, PID, PV1, ORC, NTE and OBR. The individual message segments are defined as follows: the MSH segment contains information about the message; the PID segment contains patient information; the PV1 segment contains patient location information; the ORC segment contains information related to the order (the NW indicates that the message is for a New Order); the NTE segment contains any comments attached to the order; and the OBR segment contains information related to the test that is ordered. For example, the OBR segment in Appendix E shows a "NA^Sodium" in field 4. Thus, the new order is for a Sodium (Sunquest code "NA") on patient last name "Test", first name "Enrique" (from the PID segment).

Appendix F shows another example of a successful HL7 message order sent from the WebOE system to the test area of Sunquest. This message cancels the previously requested Sodium test order (Appendix E). The "CA" in the ORC segment indicates a "Cancel" order entry request.

A slightly more complex HL7 message order entry example is shown in Appendix G. Certain laboratory orders require accompanying data in order to be processed. For example, to calculate a Creatinine Clearance, the laboratory needs both a 24-hour urine specimen, as well as a blood specimen, along with the patient's height and weight. This information can be transmitted using HL7 messages. The message in Appendix G introduces another HL7 message segment: the OBX segment. This segment is typically used to transmit laboratory test results, however, in the case of order entry, can be used to provide data that is required for processing a laboratory order request. In the case of a request for Creatinine Clearance, the OBX segment can be used to transmit both the patient Height and Weight.

The initial communications testing proves that laboratory order entry from the WebOE system is feasible. Future development work on the order entry component will require communications validation (ensure that orders received from the WebOE interface can progress through the Sunquest Laboratory Information System to completion) with the Sunquest Laboratory Information System. Once this is accomplished, the next step will be to perform high volume testing to ensure that the interface can support multiple order entry messages in a short amount of time. If the order entry interface passes high volume testing, the Sunquest order entry interface will be moved to the "Live" area, where it can be used for entering laboratory orders on actual patients.

Conclusion

Electronic results reporting and order entry is both feasible and relatively inexpensive by utilizing a Web-based interface. The major expenses involved are in server hardware and software, client hardware, the cost of a relational database management system, the cost for interfaces to the Laboratory Information System, and development costs. Software costs can be minimized by utilizing open-source (freely distributed software, with the source code also freely available) software, such as the Apache Web-server and the Perl programming language. Open-source relational database management systems are also available, and may be an option for smaller institutions and hospitals. Linux runs many popular open source relational databases on relatively inexpensive hardware. If one took a Linux, open-source software approach, server hardware and software can be obtained for under $15,000, with relatively good performance. By utilizing thin clients, client hardware costs can also be minimized.

Two interface costs were incurred for the WebOE project: $9,000 each for the results reporting and order entry interfaces. This cost was minimized due to the fact that a customized interface was not requested. If a customized interface is required, the cost could rise to over $16,000 per interface.

Even with these fixed costs, the projected returns from implementing an electronic results reporting and order entry system make this a financially worthwhile project. Designing a Web-based system with careful consideration to the problem of physician order entry will avoid the pitfalls encountered by others that doomed implementation at other institutions.

Finally, implementing a Web-based diagnostic service order entry system will position an institution for future system enhancements. For example, the popularity of hand-held computing devices will surely increase in the future, and may hold the key for wider acceptance of physician order entry. A new Wireless Application Protocol (WAP) currently allows cellular phones access to certain Web-based information. Incorporating this technology would allow both order entry and results reporting using a Web-based diagnostic service order entry system.

Additionally, hospital or institutions seeking to expand their laboratory services can use a Web-based diagnostic service order entry system to extend electronic services to clients outside the hospital or institution computer network in a secure manner. With the increasing availability of broadband individual connections (DSL and Cable modems), individual physicians should be able to quickly and easily utilize a Web-based diagnostic service order entry system. This would allow a hospital or institution to pursue an additional revenue stream.

The WebOE system can be seen as a platform for future growth and expansion. By adhering to Internet-based standards and utilizing modern software development methodologies, the WebOE system can be installed with a basic set of functionality, with additional modules and enhancements added to improve the order entry experience.

Although technologically the WebOE project appears feasible and cost-effective, end-user acceptance and utilization remain to be studied. I expect there will be high end-user acceptance for the reasons outlined in this manuscript: the target end user population (ward clerks and nurses) is receptive, and implementation should not disrupt current physician practices. I also expect high end-user utilization, due to continual end user feedback, familiarity with a browser environment, and the enhanced functionality afforded by the WebOE system.

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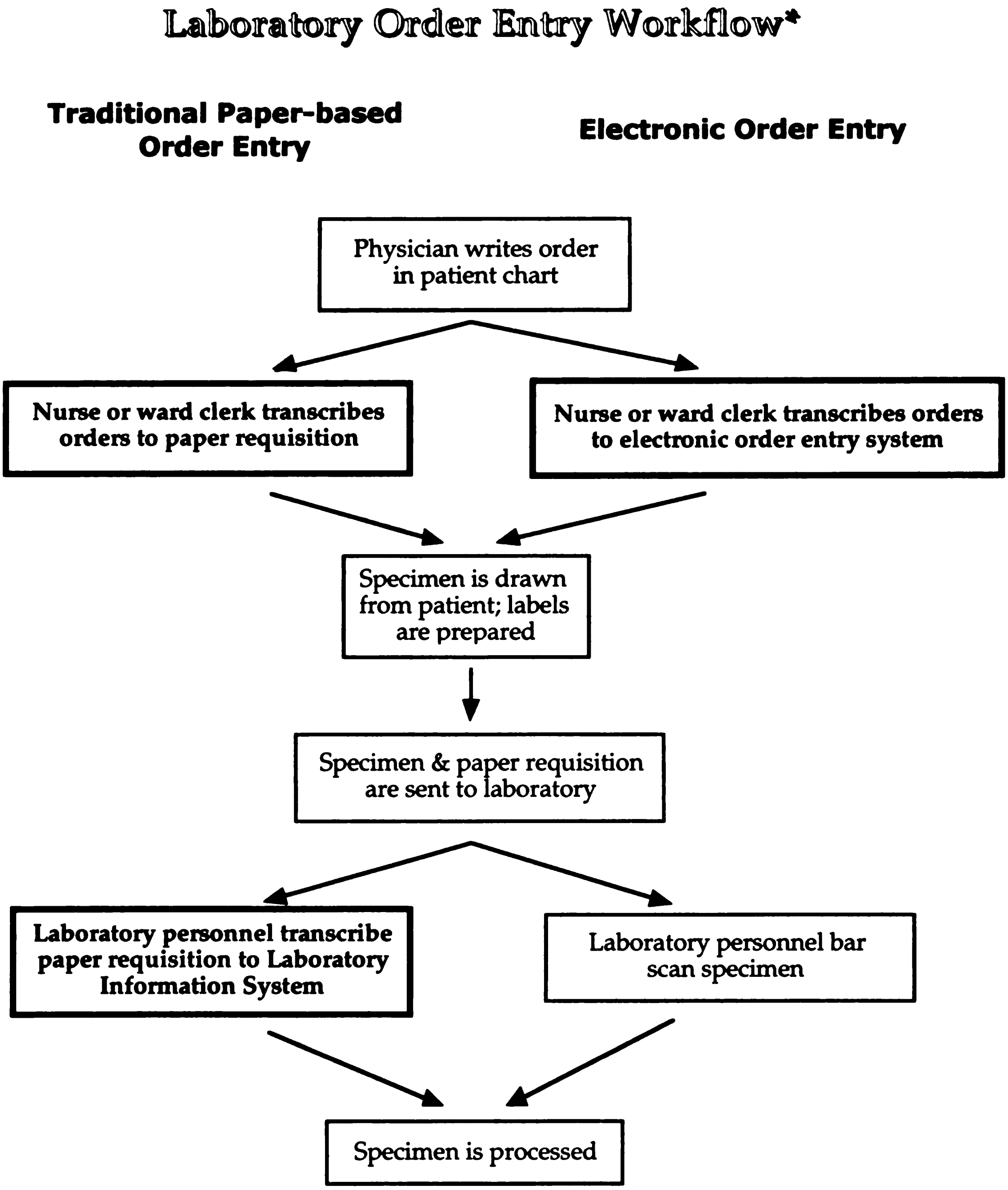
Appendices

Appendix A: Order Entry Workflow



*Note: Manual transcription steps are highlighted with bold type. The manual process requires an extra transcription step - a potential area for an error to occur.

Appendix B: Server Hardware & Server Software

Server hardware

UltraSPARC 1 model 140
128 MB RAM
2X2.1 GB scsi disk drive
2X4.2GB scsi Fast/Wide scsi disk drive
CD-ROM
12-24GB 4mm DDS-3 Tape drive
Sbus Fast/Wide SWIS/S Adapter
10/100 BaseT Fast Ethernet
Solaris 2.5.1 operating system

Server Software

Oracle Relational Database Management System 7.3.2.2
Java Development Kit JDK 1.1
Perl, version 5.005
Perl DBI version 1.09
Apache 1.2 HTTP Server
Java enabled Browser - eg: Netscape Navigator 4 or Internet Explorer 5
SPARC compiler C/C++ 4.2
Solstice Disk Suite
Solstice Backup

Appendix C: Usability Questionnaire

QUESTIONNAIRE (circle your answers)

Ia) The process of ordering clinical laboratory tests with the Web computer system is:
1. very difficult
2. moderately difficult
3. somewhat difficult
4. neither easy or difficult
5. somewhat easy
6. moderately easy
7. very easy

Ib) The process of ordering clinical laboratory tests with paper requisitions is:
1. very difficult
2. moderately difficult
3. somewhat difficult
4. neither easy or difficult
5. somewhat easy
6. moderately easy
7. very easy

IIa) The process of ordering clinical laboratory tests with the Web computer system is:
1. very slow
2. moderately slow and time consuming
3. somewhat slow
4. neither slow or fast
5. somewhat fast
6. moderately fast
7. very fast

IIb) The process of ordering clinical laboratory tests with paper requisitions is:
1. very slow
2. moderately slow and time consuming
3. somewhat slow
4. neither slow or fast
5. somewhat fast
6. moderately fast
7. very fast

IIIa) The process of ordering clinical laboratory tests with the Web computer system is:
1. very inconvenient
2. moderately inconvenient
3. somewhat inconvenient
4. neither inconvenient or convenient
5. somewhat convenient
6. moderately convenient
7. very convenient

IIIb) The process of ordering clinical laboratory tests with paper requisitions is:
1. very inconvenient
2. moderately inconvenient
3. somewhat inconvenient
4. neither inconvenient or convenient
5. somewhat convenient
6. moderately convenient
7. very convenient

IVa) The use of the Web computer system to order clinical laboratory tests was:
1. very difficult to learn.
2. moderately difficult to learn
3. somewhat difficult to learn
4. neither easy or difficult to learn
5. somewhat easy to learn
6. moderately easy to learn
7. very easy to learn

IVb) The use of paper requisitions to order clinical laboratory tests was:
1. very difficult to learn.
2. moderately difficult to learn
3. somewhat difficult to learn
4. neither easy or difficult to learn
5. somewhat easy to learn
6. moderately easy to learn
7. very easy to learn

COMMENTS: Please use this space to discuss any negative or positive aspects of the Web ordering system

____

____

____

____

____

Appendix D: UCSF Laboratory Order Requisition

CLINICAL LABORATORIES

Use separate form for each specimen type (blood, urine, CSF, etc.) Use special forms for Emergency, Blood Bank or Microbiology.

PLEASE PRESS FIRMLY WITH BALL POINT PEN WHEN FILLING OUT FORM.

LABORATORY CONSULTATION

UCSF STANFORD HEALTH CARE
UCSF Medical Center
San Francisco, CA

CLINICAL LABORATORIES

701-020 (6/99)

L B S G N	RECEIVE	ENTER	PHYSICIAN'S NAME (Print)	M.D. #	EXT. or BEEPER
			SEND REPORT TO:		
	LABEL	ALIQUOT	SPECIMEN COLLECTION Date: ______	Time: ______ Use 24 hour clock	
			PHONE/FAX RESULTS (only if no CRT) TO:		

UNIT NUMBER

PT. NAME

BIRTHDATE

LOCATION DATE

BUDGET ACCT. NO.:

MEDICAL NECESSITY AND ICD-9 CODES (REQUIRED FOR OUTPATIENTS ONLY)

Medicare (and, increasingly, other insurers) will only pay for services that are reasonable and necessary for the diagnosis and treatment of the patient. The physician must specify an ICD-9 diagnostic code to indicate the medical necessity of *each* test requested. Medicare and other carriers may not pay for screening tests or tests that are not FDA-approved. If there is reason to believe that a carrier will not pay for a test, the patient should be informed and asked to sign an Advanced Beneficiary Notice (ABN) indicating acceptance of responsibility for the cost of the test if the carrier denies payment. See back of form for an explanation of **(LMRP)**.

Write the ICD-9 diagnosis code(s) for this patient in the numbered spaces below, then check off the tests desired.

1. ________ 2. ________ 3. ________ 4. ________ 5. ________

HEMATOLOGY

Is the patient receiving Heparin? ☐ Coumadin? ☐

CBC	CBC (includes Platelet Count) (LAV)
CBCD	CBC with Diff. & Platelets (LAV)
PLT	Platelet Count (LAV)
PT	Prothrombin Time (BLU)
PTT	Part. Thromboplastin Time (BLU)
RET	Reticulocyte Count (LAV)
ESR	Sedimentation Rate (LAV)
CLIP	Cardiolipin Antibodies (BLU)
F5	Factor V Activity (BLU)
F8	Factor VIII Activity (BLU)
FDD	Fibrin D-Dimers (BLU)
FIB	Fibrinogen (BLU)
RVVT	Russell's Viper Venom Test (BLU)

OTHER BLOOD TESTS
COLLECT SERUM IN GEL TUBE UNLESS OTHERWISE SPECIFIED

LYTE	Electrolytes (Na, K, Cl, CO_2 - GRN OK)
NA	Sodium (GRN OK)
K	Potassium (GRN OK)
CL	Chloride (GRN OK)
CO2	CO_2, Total (GRN OK)
CR	Creatinine
CA	Calcium, Total

ACTH	ACTH (Special tube on ice)
ALB	Albumin
ALKP	Alkaline Phosphatase
AFPT	Alpha-Fetoprotein (Non-Prenatal)
ALT	Alanine Aminotransferase
NH3	Ammonia (GRN on ice)
AMY	Amylase
ANA	Anti-Nuclear Antibody
AST	Aspartate Aminotransferase
BILD	Bilirubin, Direct-reacting
BILT	Bilirubin, Total
BUN	Urea Nitrogen
C3	C3 Complement component
C4	C4 Complement component
CZP	Carbamazepine
TBHS	CD3(T), CD19(B) and NK Cells, with CD4/CD8 (H/S) Ratio (LAV) - requires CBC w/Diff
THI	CD4 (Helper-Inducer) T Cells (LAV) - requires CBC w/Diff
CEA	Carcinoembryonic Antigen
CH50	CH50 (Complement, Total)
CHOL	Cholesterol, Total
HDL	Cholesterol, HDL
LDL	Cholesterol, LDL (incl. tot. and HDL chol., trig.) – 12 hour fast required

CK	CK, Total
MBMU	CK-MB (Order CK, Total separately)
CMVD	CMV Antibody
DCT	Coombs, Direct (LAV)
CORT	Cortisol
CYCL	Cyclosporine (GRN)
DIG	Digoxin
ADNA	DNA Antibody (Anti-DNA)
FERR	Ferritin
FOLR	Folate, RBC (LAV)
FSH	Follicle Stimulating Hormone
GENT	Gentamicin
GGT	Gamma-glutamyl Transpeptidase
FBS	Glucose Fasting
GLU	or Describe: ______
GH	Growth Hormone
HCGP	HCG for pregnancy
HCGT	HCG for tumor
HBA1	Hemoglobin A1c (LAV)
HBEP	Hemoglobinopathy Evaluation (LAV) - includes A_2 and F
HEPATITIS TESTING (Diagnostic Use)	
HAVM	HAV IgM Antibody (Acute)
CORM	HBc IgM Antibody (Acute)
CORE	HBc Total Antibody (Chronic)

HBAG	HBsAg (Acute or Chronic)
HBAB	HBs Antibody (Immunity)
HCV	HCV Antibody (Acute or Chronic)
MONO	Heterophile Agglutinins
HIV	HIV-1 & -2 Antibody (requires consent form) (PK)
HIVB	HIV-1 RNA, Quantitative, by branched-chain DNA (requires consent form) (LAV-10mL)
IFE	Immunofixation Electrophoresis
IGA	IgA, Quantitative
IGE	IgE, Quantitative
IGG	IgG, Quantitative
IGM	IgM, Quantitative
IRON	Iron
FE	Iron, Transferrin & Saturation
LACT	Lactate (GRY on ice)
LD	Lactic Dehydrogenase
LEAD	Lead (NAVY w/LAV label)
LIPA	Lipase
LI	Lithium
LH	Luteinizing Hormone
MG	Magnesium
MTX	Methotrexate
NEON	Neonatal Screen (PKU, T4, etc.)
OSM	Osmolality
PTH	Parathormone (including Calcium)
PBAR	Phenobarbital
PHNY	Phenytoin
PO4	Phosphorus
PROC	Procainamide (including NAPA)
NPROG	Progesterone
PROL	Prolactin
PRSA	Prostate Specific Antigen **(LMRP)**
PE	Protein Electrophoresis

TP	Protein, Total
RF	Rheumatoid Factor
RPR	RPR, Routine
RPRN	RPR, Prenatal
RUBI	Rubella Antibody
SAL	Salicylate
PTES	Testosterone
THEO	Theophylline
TGL	Thyroglobulin (includes Anti-Thyroglobulin Antibodies)
TSH	Thyrotropin
FT4	Thyroxine, Free
TOBR	Tobramycin
TOXO	Toxoplasma IgG Antibody
TIGM	Toxoplasma IgM & IgG Antibody
TRFN	Transferrin
TRIG	Triglycerides - 12 hr fast required
TRPI	Troponin I (GRN)
URIC	Uric Acid
VALP	Valproic Acid
VANC	Vancomycin
VB12	Vitamin B12

OTHER TESTS

Look up abbreviations or names on back of form or in on-line lab manual. Copy them exactly below. Please do not make up your own abbreviations. They may have a different meaning in the laboratory!

Appendix E: WebOE New Order HL7 Message

```
MSH|^~\&|1|ZEVI|SQOE|SQ|199910141352||ORM^001|199910140000004|T|2.2|
PID|||32919154^^^1||TEST^ENRIQUE|||||||||||||1234567
PV1||OP|CATH^^||||12624||||||||||23311||1234567
ORC|NW||||||||||||11L^1105^B|||
NTE|||Gee, isn't this nice?
OBR||19991014P0000004||NA^SODIUM|||199910111200|||||||||23311|||||||||||
^^^^^S
```

Appendix F: WebOE Cancel Order HL7 Message

```
MSH|^~\&|1|ZEVI|SQOE|SQ|199910141354||ORM^001|199910140000005|T|2.2|
PID|||32919154^^^1||TEST^ENRIQUE|||||||||||||1234567
PV1||OP|CATH^^||||12624||||||||||23311||1234567
ORC|CA||||||||||||11L|||
OBR||19991014P0000005||NA^SODIUM|||199910111200|||||||||23311|||||||||||
^^^^^S
```

Appendix G: WebOE RESOE HL7 Message

```
MSH|^~\&|1|ZEVI|SQOE|SQ|199910271159||ORM^001|199910270000007|T|2.2|
PID|||32919154^^^1||TEST^ENRIQUE|||||||||||||1234567
PV1||OP|CATH^^||||12624||||||||||23311||1234567
ORC|NW||||||||||||11L|||
NTE|||
OBR||19991027P0000007||CRCL^CREATININE
CLEARANCE|||199910271000|||N||||23311|||||||||||^^^^^
OBX|||HT^HEIGHT (INCH)||70
OBX|||WT^WEIGHT (LBS)||150
```

Tables

Table A: Benefits of Electronic Physician Order Entry

1) Reduced need for clerks to manually transcribe chart orders to a series of paper requisitions and into disparate hospital information systems
2) Reduced costs of printing multi-part paper requisitions
3) Reduced costs of tracking and storing paper requisitions
4) Reduced time generating repetitive order lists and protocol orders
5) Reduced number of unnecessary duplicate orders
6) Reduced number of lost orders
7) Reduced number of ambiguous orders
8) Enhanced ability to place orders from any location inside or outside the medical center
9) Faster transmission of orders to diagnostic clinical services
10) Support of clinical decision making and promotion of cost-effective ordering practices (by providing on line information and feedback), etc.

Table B: Browser Interface Features to Support Order Entry

1) Requires manual entry of little or no patient demographic information
2) Is designed according to end user feedback and preferences
3) Provides up front point and click ordering of the most commonly needed diagnostic services on any given nursing station or clinic
4) Automates repetitive protocol orders
5) Immediately generates labels with the information required to process certain laboratory tests (e.g., labels specifying type of blood tube and quantity of blood required)
6) Can be run by cheap and compact network computers that are readily accessible.

Table C: LMRP Rules for Partial Thromboplastin Time (PTT)

ICD9 Code	Diagnosis
260	Kwashiorkor
261	Nutritional marasmus
262	Other severe protein-calorie malnutrition
263.0-263.1	Other and unspecified protein-calorie malnutrition
286.0-286.7	Coagulation defects
286.9	Other and unspecifiedcoagulation defects
287.8-287.9	Other specified and unspecified hemorrhagic conditions
289.8	Other specified diseases of blood and blood-forming organs
415.11	Pulmonary embolism and infarction
415.19	
579.0-579.4	Intestinal malabsorption
579.8	
782.7	Spontaneous ecchymoses
790.92	Abnormal coagulation profile
998.11	Hemorrhage complicating a procedure
V123	Personal history of diseases of blood and blood-forming organs
V183	Family history of other blood disorders
V586.1	Long-term (current) use of anticoagulants. Note: heparin

Table D: Barriers to Implementing Web-based diagnostic service order entry

1) Technical barriers – historically systems have been complex and difficult to master and modify for local users' needs
2) Economic barriers – installation and maintenance costs are substantial
3) Social barriers – implementation often requires dramatic changes to physician work habits
4) Political barriers – difficult to come to agreement on a system that will satisfy all users' needs
5) Logistical barriers – challenges to changing workflow and installation, maintenance, and placement of computer workstations

Table E: Benefits from Web-based diagnostic service order entry

1) Reduction in laboratory errors (number of lost orders, ambiguous orders, duplicate orders, and illegible orders)
2) Decreased time required by diagnostic services to process orders
3) Ability to place orders from any location in the medical center
4) Reduction in costs and effort of printing, storing, and distributing paper requisitions
5) Customizable user interface tailored to the needs of the local users and diagnostic services
6) Minimization of technical and economic obstacles associated with past generation order entry systems.

Table F: Strategy for Qualitative and Quantitative Evaluation

1) Conduct appropriate training of end-users
2) Observe end users utilizing WebOE for a two week trial period
3) Administer a questionnaire to end users
4) Measure qualitative assessment of WebOE
5) Refine and improve WebOE
6) Install WebOE in a hospital ward and allow end-users to use system of choice (WebOE or paper-based system) for a 4-week time period
7) Measure quantitative differences between the two systems (mean turnaround time, number of tests ordered, error rate)

Table G: Customization of WebOE results reporting display

1) Provide all new results for my current patients since the last sign-on
2) Provide the results list in reverse chronological order, sorted by date and time resulted, not by date and time ordered.
3) Provide results for the selected patient or all my current patients only in the last 24 hours.

Figures

Figure 1: System Architecture

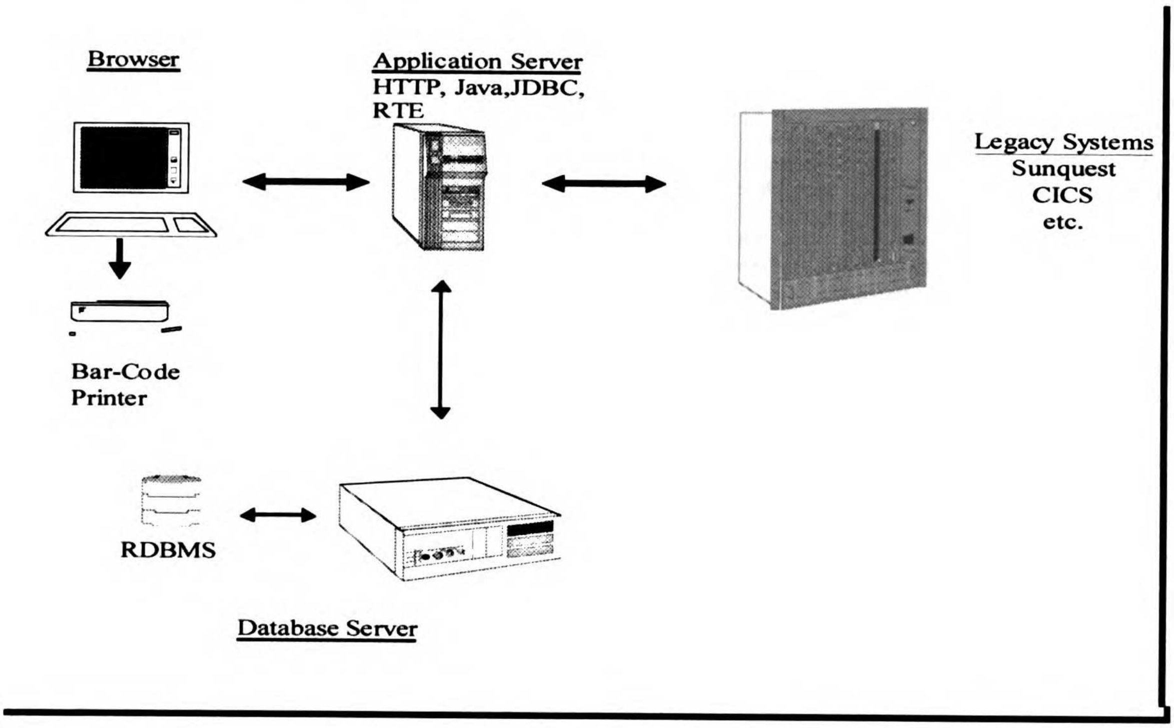


Figure 2: Firewall Security

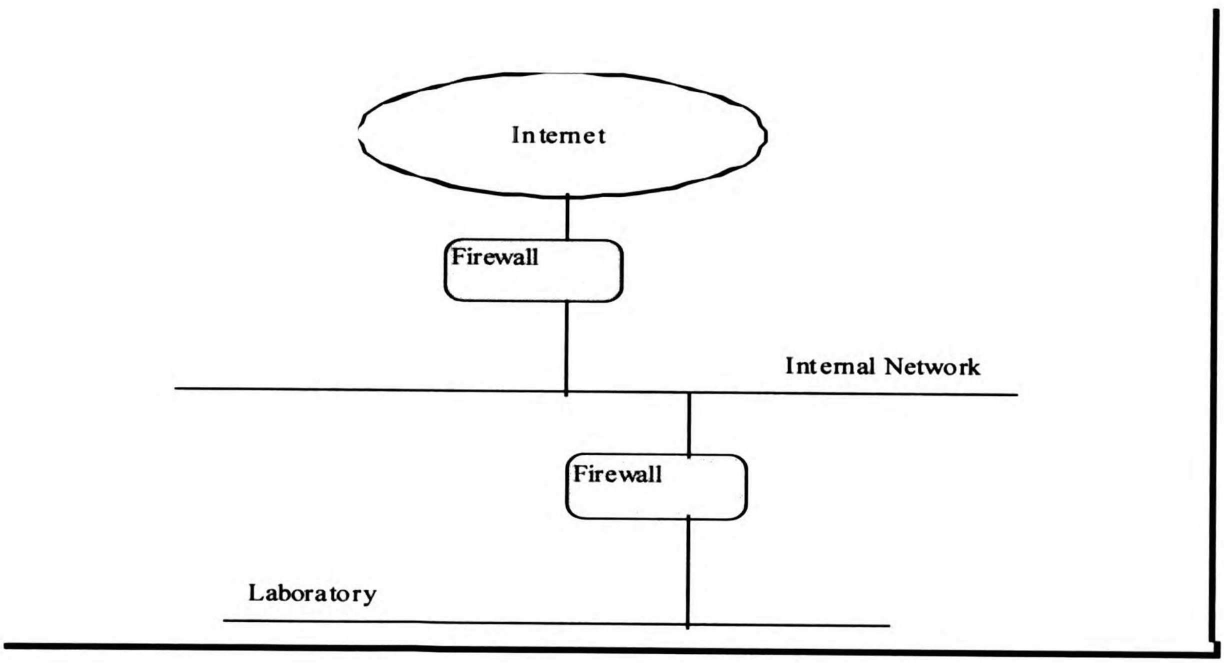


Figure 3: STOR Initial User Screen

```
     MAR 31, 2000                                          [redacted]
******************************************************************************
                               OPTIONS AVAILABLE

      1.  Laboratory                           12.  All Clinic Visits & Reports
      2.  Xray/Nuclear Medicine                13.  Clinic Visits
      3.  Operative Diagnosis                  14.  Microbiology
      4.  Hospitalization                      15.  Problems (outpatient)
      5.  Cytology                             16.  Therapies (outpatient)
      6.  Pathology                            17.  EKG
      7.  Laboratory (for past dates)          18.  Roster of Patients
      8.  Flow (make a flowsheet)              19.  PFT (Pulmonary Function)
      9.  Suggestions & comments               20.  Health Care Maint/DX Protocols
     10.  Demographics                         21.  Lab Man, OR Sys, MELVYL, MMedex
     11.  Graph (make a graph)                 22.  History & Physical
                                               23.  MD Directory

******************************************************************************
     Help Desk: 353-9000.    At ANY Prompt:  Type  ?  for help,  Q  to quit.
                   STOR/CDS Web Page:  http://itsa.ucsf.edu/~stor
******************************************************************************

Enter option:
```

Figure 4: STOR - Laboratory Results Selection

```
******************************************************************************
                               OPTIONS AVAILABLE

      1.  Laboratory                           12.  All Clinic Visits & Reports
      2.  Xray/Nuclear Medicine                13.  Clinic Visits
      3.  Operative Diagnosis                  14.  Microbiology
      4.  Hospitalization                      15.  Problems (outpatient)
      5.  Cytology                             16.  Therapies (outpatient)
      6.  Pathology                            17.  EKG
      7.  Laboratory (for past dates)          18.  Roster of Patients
      8.  Flow (make a flowsheet)              19.  PFT (Pulmonary Function)
      9.  Suggestions & comments               20.  Health Care Maint/DX Protocols
     10.  Demographics                         21.  Lab Man, OR Sys, MELVYL, MMedex
     11.  Graph (make a graph)                 22.  History & Physical
                                               23.  MD Directory

******************************************************************************
     Help Desk: 353-9000.    At ANY Prompt:  Type  ?  for help,  Q  to quit.
                   STOR/CDS Web Page:  http://itsa.ucsf.edu/~stor
******************************************************************************

Enter option: 1   SHOW LABORATORY
  Patient: 99999999
```

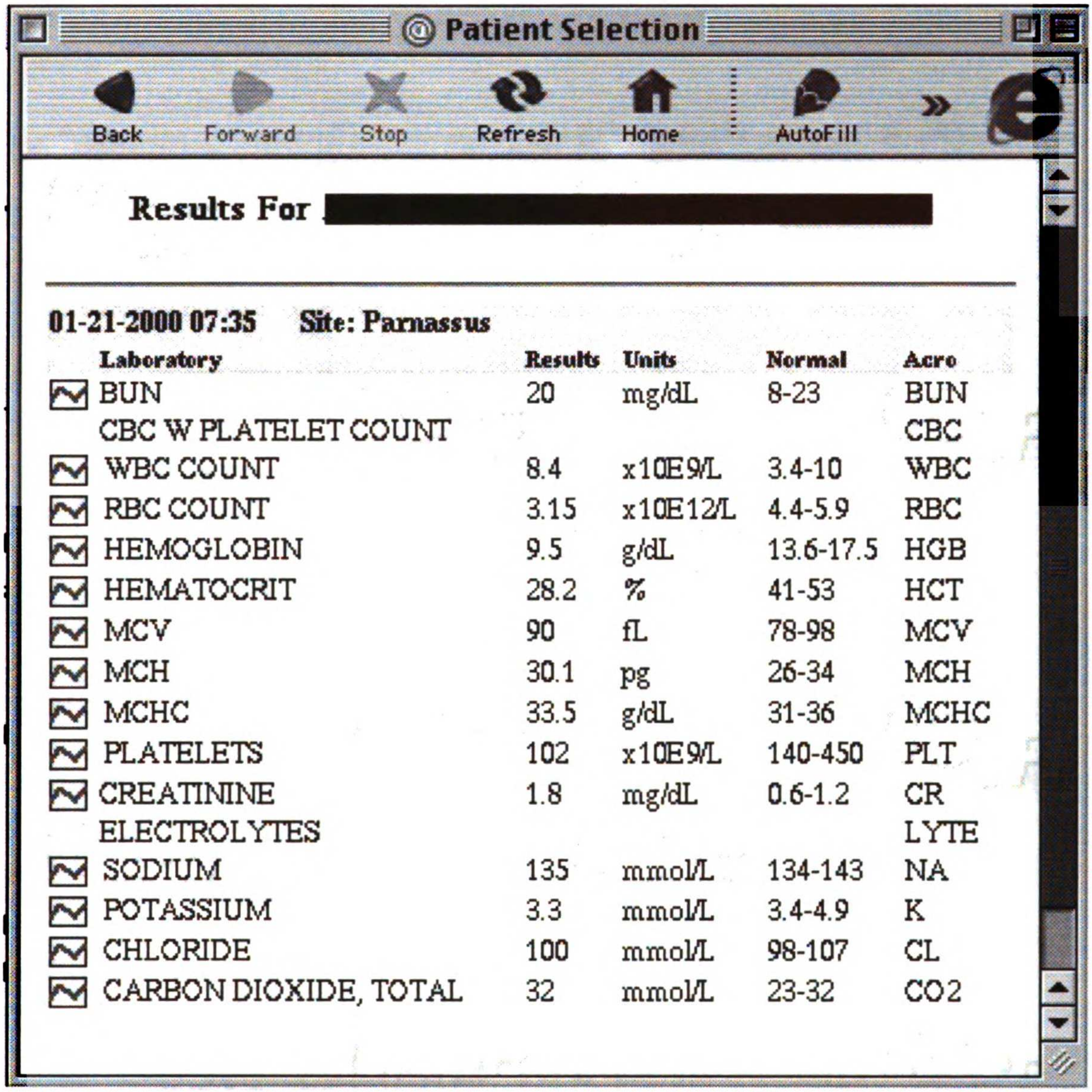
Figure 5: STOR - Laboratory Results

```
[redacted]                    [redacted]                [redacted]
================================================================================
                 * = abnormal   # = system cannot determine normal
SITE   DATE   TIME  LABORATORY              RESULTS    UNITS     NORMAL     ACRO
================================================================================
PARN  1-31-00 14:28 CBC W/PLATELET COUNT                                    CBC
                      WBC COUNT               8.5      x10E9/L   3.4-10     WBC
                      RBC COUNT             * 3.50     x10E12/L 4.4-5.9     RBC
                      HEMOGLOBIN            * 10.7     g/dL      13.6-17.5  HGB
                      HEMATOCRIT            * 32.0     PERCENT   41-53      HCT
                      MCV                     92       fL        78-98      MCV
                      MCH                     30.7     pg        26-34      MCH
                      MCHC                    33.5     g/dL      31-36      MCHC
                      PLATELETS               417      x10E9/L   140-450    PLT
                    CREATININE              * 2.2      mg/dL     0.6-1.2    CR
      1-21-00 07:35 CBC W/PLATELET COUNT                                    CBC
                      WBC COUNT               8.4      x10E9/L   3.4-10     WBC
                      RBC COUNT             * 3.15     x10E12/L 4.4-5.9     RBC
                      HEMOGLOBIN            * 9.5      g/dL      13.6-17.5  HGB
                      HEMATOCRIT            * 28.2     PERCENT   41-53      HCT
                      MCV                     90       fL        78-98      MCV
                      MCH                     30.1     pg        26-34      MCH
(Q=Quit, <Return>=Continue, P=Patient, C=Copy to ptr, ?=Help): █
```

Figure 6: STOR - Laboratory Results Part 2

```
[redacted]                    [redacted]                [redacted]
================================================================================
                 * = abnormal   # = system cannot determine normal
SITE   DATE   TIME  LABORATORY              RESULTS    UNITS     NORMAL     ACRO
================================================================================
PARN  1-21-00 07:35   MCHC                    33.5     g/dL      31-36      MCHC
                      PLATELETS             * 102      x10E9/L   140-450    PLT
                    UREA NITROGEN             20       mg/dL     8-23       BUN
                    CREATININE              * 1.8      mg/dL     0.6-1.2    CR
                    ELECTROLYTE PANEL                                       LYTE
                      SODIUM                  135      mmol/L    134-143    NA
                      POTASSIUM             * 3.3      mmol/L    3.4-4.9    K
                      CHLORIDE                100      mmol/L    98-107     CL
                      CARBON DIOXIDE, TOTAL   32       mmol/L    23-32      CO2
      1-20-00 06:30 CBC W/PLATELET COUNT                                    CBC
                      WBC COUNT               9.9      x10E9/L   3.4-10     WBC
                      RBC COUNT             * 3.09     x10E12/L 4.4-5.9     RBC
                      HEMOGLOBIN            * 9.5      g/dL      13.6-17.5  HGB
                      HEMATOCRIT            * 28.6     PERCENT   41-53      HCT
                      MCV                     93       fL        78-98      MCV
                      MCH                     30.8     pg        26-34      MCH
                      MCHC                    33.2     g/dL      31-36      MCHC
(Q=Quit, <Return>=Cont, P=Patient, B=Back up, C=Copy to ptr, ?=Help): █
```

Figure 7: WebOE Results Screen



@ Patient Selection

Back Forward Stop Refresh Home AutoFill

Results For [redacted]

01-21-2000 07:35 Site: Parnassus

Laboratory	Results	Units	Normal	Acro
BUN	20	mg/dL	8-23	BUN
CBC W PLATELET COUNT				CBC
WBC COUNT	8.4	x10E9/L	3.4-10	WBC
RBC COUNT	3.15	x10E12/L	4.4-5.9	RBC
HEMOGLOBIN	9.5	g/dL	13.6-17.5	HGB
HEMATOCRIT	28.2	%	41-53	HCT
MCV	90	fL	78-98	MCV
MCH	30.1	pg	26-34	MCH
MCHC	33.5	g/dL	31-36	MCHC
PLATELETS	102	x10E9/L	140-450	PLT
CREATININE	1.8	mg/dL	0.6-1.2	CR
ELECTROLYTES				LYTE
SODIUM	135	mmol/L	134-143	NA
POTASSIUM	3.3	mmol/L	3.4-4.9	K
CHLORIDE	100	mmol/L	98-107	CL
CARBON DIOXIDE, TOTAL	32	mmol/L	23-32	CO2

Figure 8: Viewing of Historical Laboratory Values

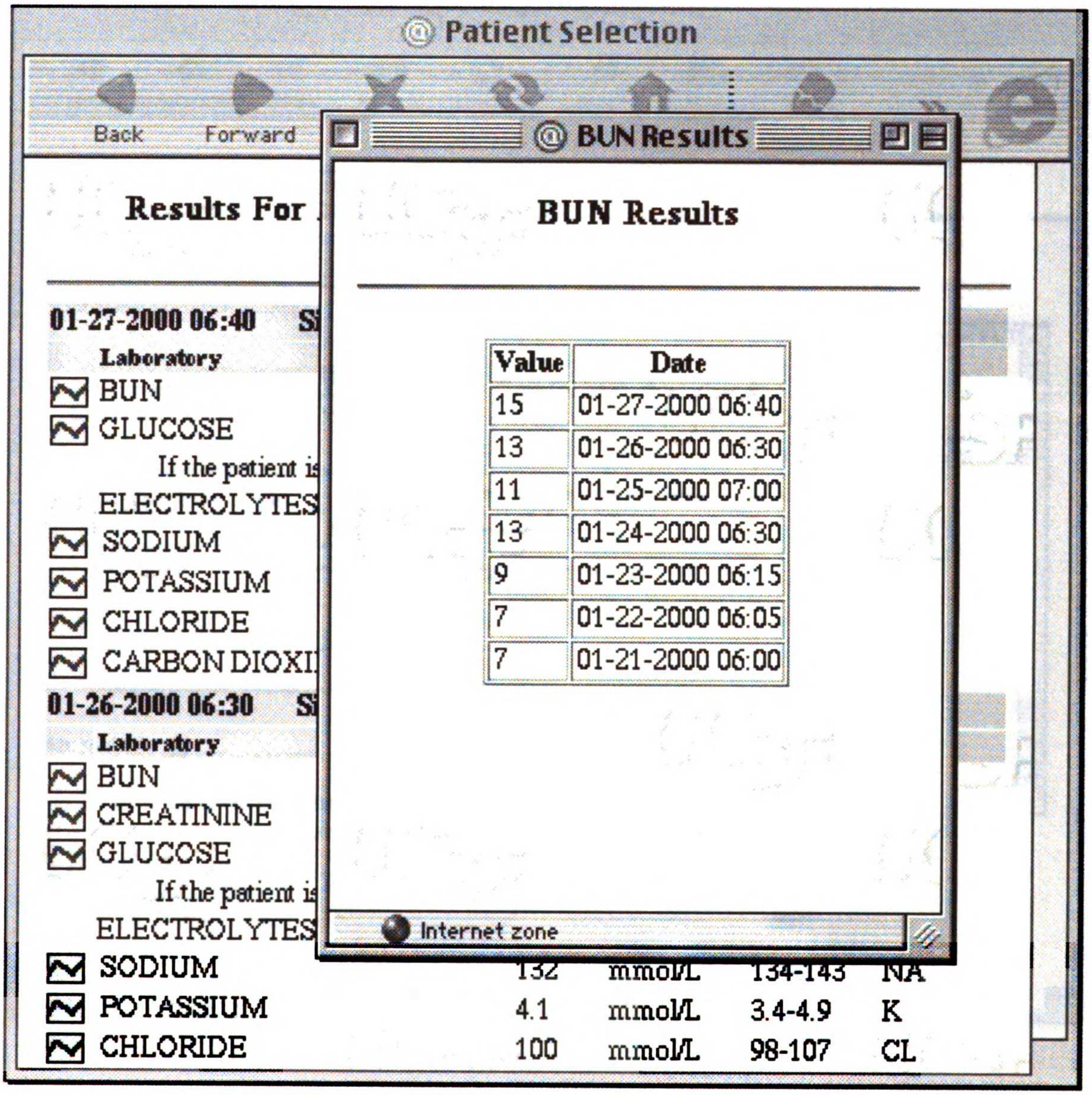


Figure 9: WebOE Order Entry Component

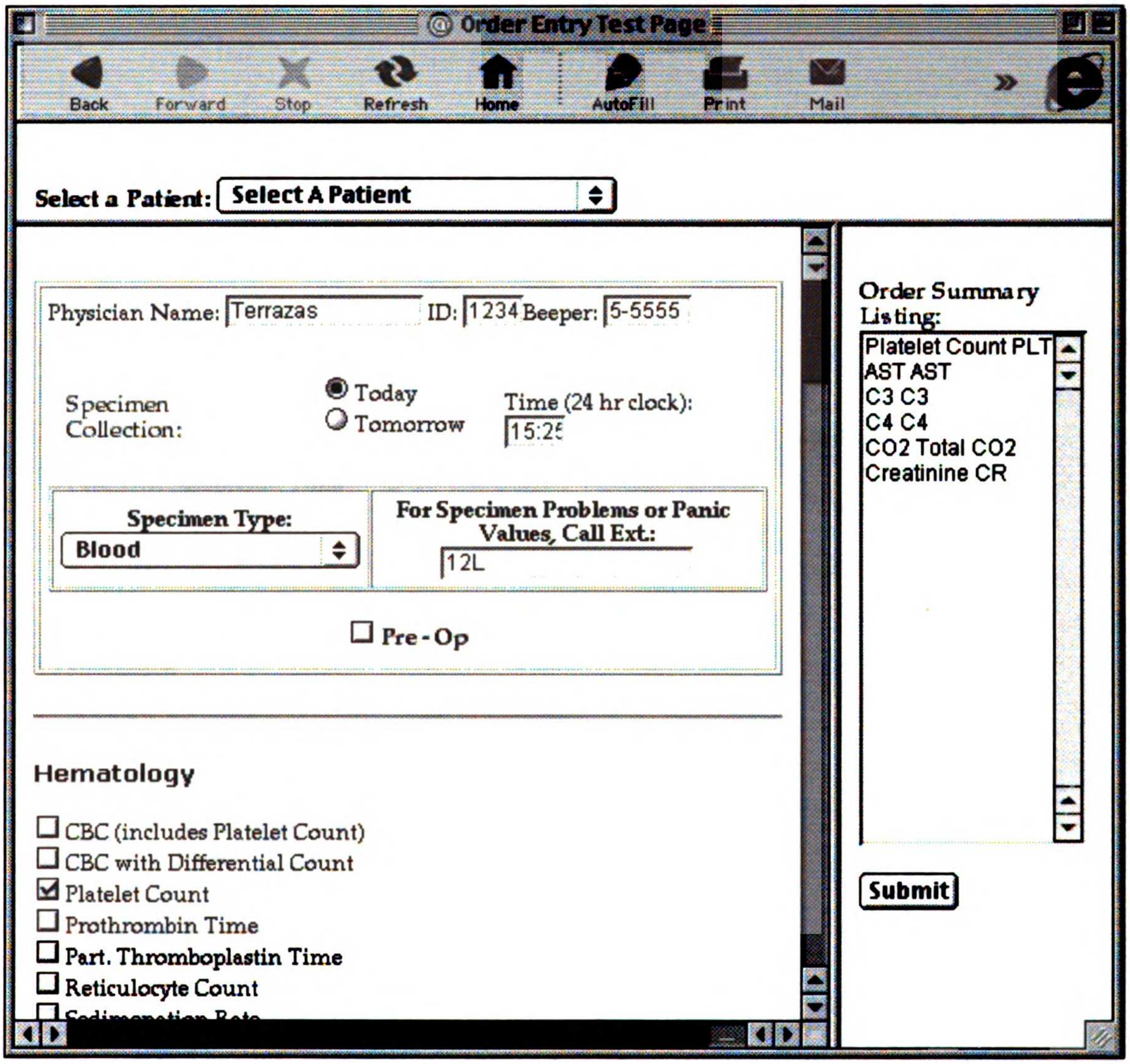


Figure 10: Order Entry Component - Hematology

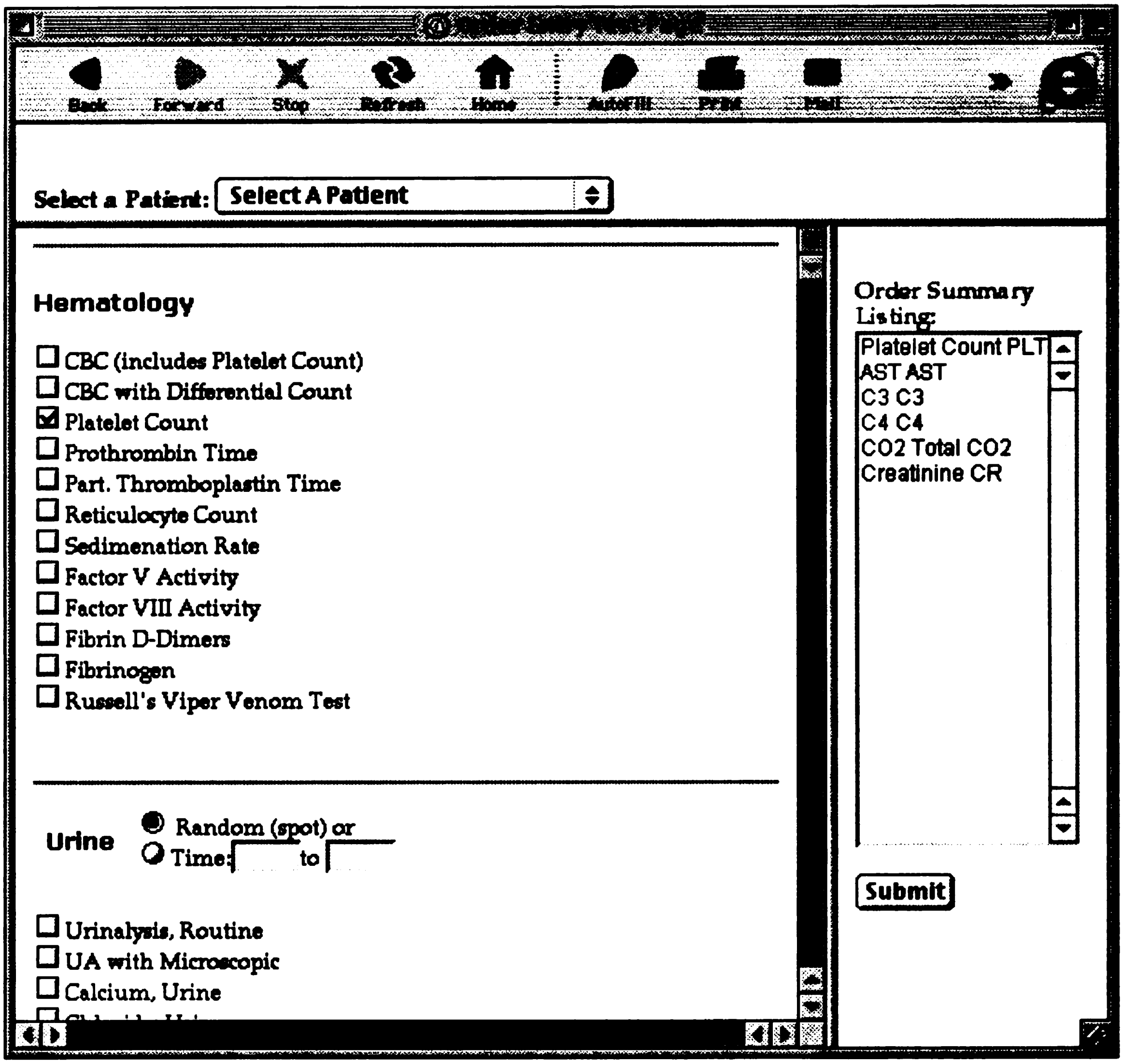


Figure 11: Order Entry Component - Urine

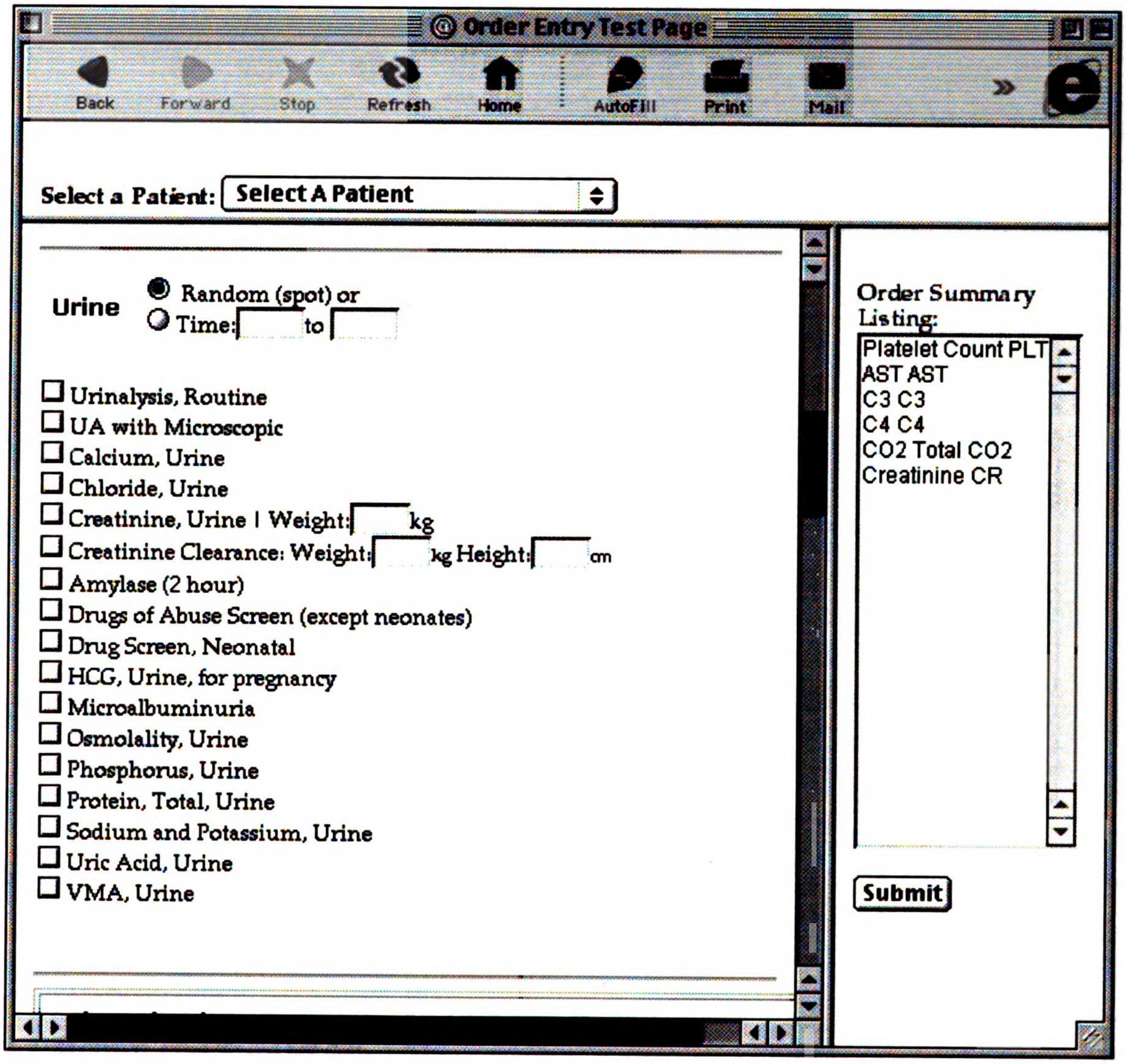


Figure 12: Order Entry Component - Other Blood Tests

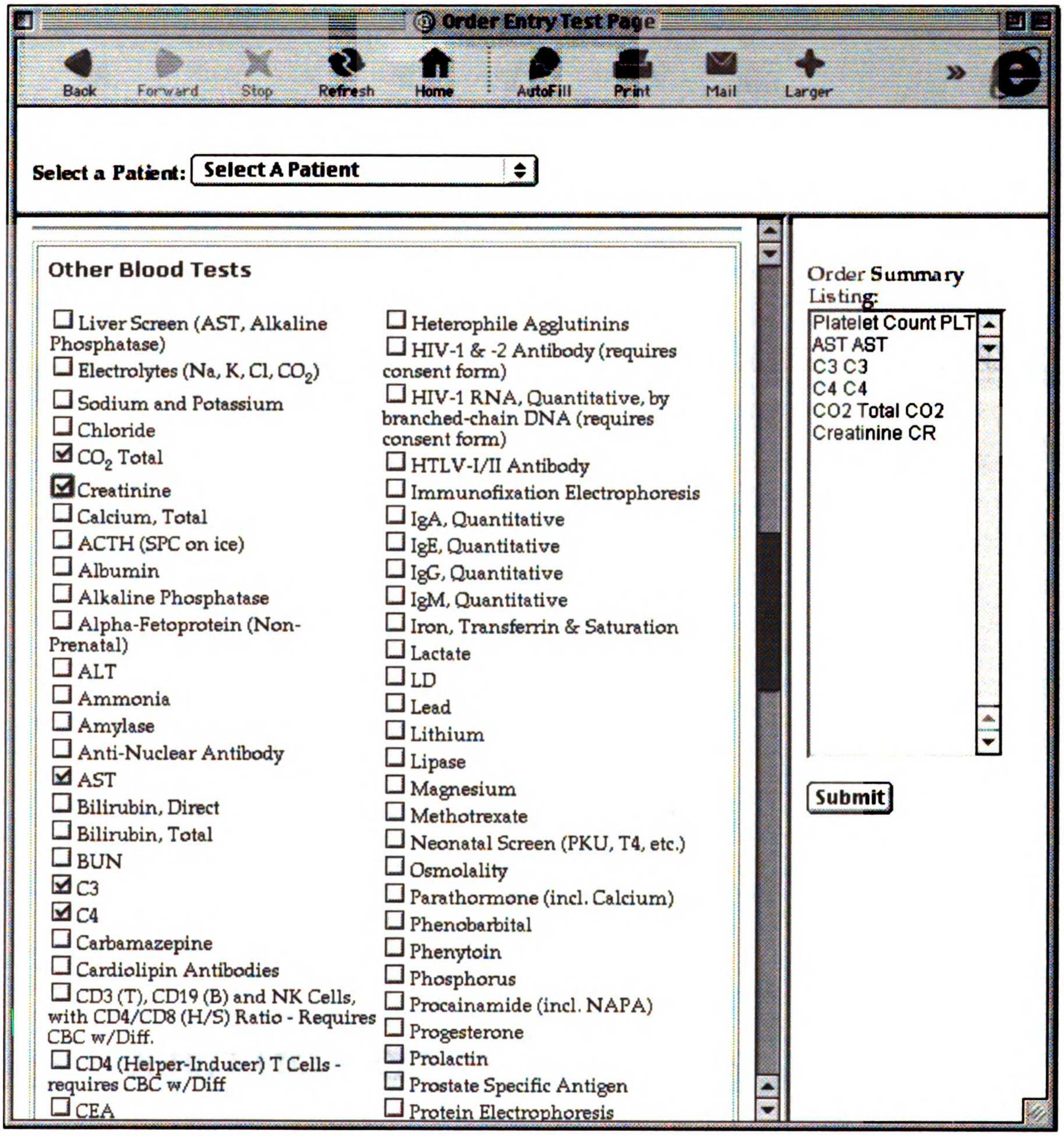


Figure 13: Order Entry Component - Other Body Fluids and CSF