Comprehensive Graphic-Based Display of Clinical Pathology Laboratory Data

John Bernard Henry, MD, and Karen C. Kelly

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Abstract

In this age of ever-increasing demands for and uses of patient data, technologic advancements in the form of electronic patient records permit improved data access and prompt retrieval of higher quality patient care data, with more versatility in display, facilitating the integration of information concerning patients over time and between settings of care, which is in turn more accessible for use by practitioners and provides more efficient and effective decision support in areas of patient care.

The graphic display of laboratory data is central to the evolving computerized patient record and needs to be taken into careful consideration along with clinician perception and ease of data interpretation in redesigning the graphic reporting of numeric clinical pathology laboratory data. An ideal system should generate user-friendly, graphic-based comprehensive reports highlighting abnormalities with trends for diagnosis, clinical management, and risk-factor detection.

We have come a long way in the evolution of laboratory results reporting from the application of overlapping laboratory requests with results to photocopying cumulative reports,[1] through several generations of the current iteration of a computerized numeric display of clinical laboratory data.[2] In the past, lack of attention to issues of graphic perception resulted in the use of data displays that convey quantitative information inadequately and in graphic methods that are ineffective.

More than 8 years ago, Powsner and Tufte[3] published their landmark article on graphic reporting, which included a graphic prototype of a single laboratory measurement. Surprisingly, there has been virtually no subsequent implementation in laboratory information systems.

The purpose of this report is to promote a graphic-based, comprehensive, lifetime display of patients' numeric clinical pathology laboratory data, with an emphasis on patient care services within the hospital and ambulatory settings in a nonlinear, time-sequential mode to identify trends for diagnosis, management, treatment, and risk-factor detection. Advancement and enhancement of the graphic reporting of numeric laboratory results that permit clinicians to better use and understand laboratory data while maintaining brevity in a comprehensive, consolidated, computerized lifetime medical record will be offered.

Considerations

Just as timeliness is a quality attribute and strategy in terms of laboratory results reporting,[4] equally important is the format of presentation of clinical laboratory data in clinical pathology. Graphs are exceptionally powerful tools for data

analysis that can lead to a deeper understanding of laboratory data. Unfortunately, the tremendous growth in the quantity and variety of laboratory measurements has resulted in an increase in the thickness of the typical patient medical record, making it virtually impossible for a clinician to grasp and trend all of a patient's salient inpatient and outpatient data. Simplifying the structure of encoded laboratory data via the use of graphic displays in a comprehensive, succinct laboratory report would permit a more effective framework for decoding pertinent information and drawing inferences, which then can be combined with clinicians' prior medical knowledge to more quickly draw appropriate conclusions; this would be highly beneficial to efficient and effective patient care and would be an excellent service to clinician customers.

The ever-increasing presence of the long-term, computerized patient medical record,[5] as evidenced by our own institution's hospital information system's goal to maintain electronic data input for the lifetime of each patient (C. Szenczy, Chief Information Officer, Information Management Technologies, State University of New York Upstate Medical University, oral communication, September 10, 1998), represents an enormous amount of cumulative data that will need to be summarized, trended, and consolidated in an optimal manner over an individual's lifetime. The display of such clinical pathology laboratory data should not be limited to a single instance or time frame (eg, a single hospital admission or a series of ambulatory visits over a 1-month period), but should include data collected periodically in all settings. Ambulatory and hospital admission results may be embraced separately, or data from the 2 settings may be combined, with inpatient and outpatient visits integrated and combined into a single computerized medical record.

Accuracy and precision in association with quality control and quality assurance have earned the respect and trust of our clinical colleagues with regard to laboratory data. Hence, graphic-based reporting of clinical laboratory information should incorporate the precision or variability within each laboratory determination. Measurements vary even when all controllable preanalytic and postanalytic variables are kept constant because of uncontrollable analytic variables or measurement error. Thus, an important function of any graphic display is to account for this variation by clearly distinguishing what reflects a change in the patient from a change in the laboratory measurement.

Population reference values coupled with numerous, sequential determinations of an analyte defining an individual's "normal" value enhance the value of trend interpretation in risk factor identification, as do multiple laboratory test results related to a particular medical diagnosis or condition as highlighted in pertinent organ or disease panels.[6] Grouping several graphic displays of different analytes on 1 page (eg, a lipid panel) helps elucidate a diagnosis by organizing the information most desirable and relevant for managing the patient's disease.[6,7]

The graphic display of laboratory data via the use of trends for individual laboratory measurements and examinations, when associated with a disease, will only further enhance the efficient use of clinical pathology laboratory data by clinicians.

Materials and Methods

Data were obtained for a man during a 7-year period for both ambulatory visits and hospital admissions. This information, derived from the patient's cumulative summary reports, was entered into a spreadsheet (Microsoft Excel 2001, Microsoft, Redmond, WA).

With this patient information on hand, Powsner and Tufte's[3] basic graph of a single laboratory measurement was used as the starting point for the development of our new graphic prototype. The patient's analyte measurements each were depicted in their own prototype graphic **Figure 1**, and later grouped into specific organ or disease panels, such as

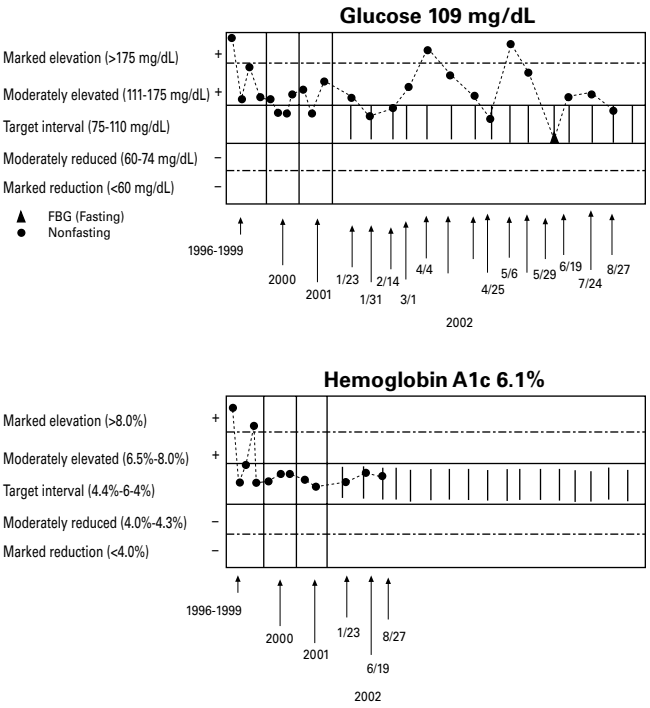

Figure 1 Prototype graphic display: glucose and hemoglobin A_{1c}. Values are given as conventional units. To convert the conventional units for glucose to Système International (SI) units (mmol/L), multiply by 0.05551; to convert the conventional units for hemoglobin A_{1c} to SI units (proportion of 1.0), multiply by 0.01. Modified from Powsner SM, Tufte ER. Graphical summary of patient status. *Lancet.* 1994;344:386-389.

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the basic metabolic, hepatic function, and lipid American Medical Association (AMA)-designated organ panels **Figure 2**, **Figure 3**, **Figure 4**, as well as 2 others **Figure 5** and **Figure 6**.

Specific targeted reference values for each analyte were devised from various sources[7,8] and incorporated into the ordinate of the graphics, along with the magnitude of elevation or reduction of each measurement, with time, including specific times for the most recent or current year, on the abscissa.

Dividing lines were used to more quickly and clearly pinpoint to which specific reference interval each of the patient's analyte measurements corresponded. Last, the individual analyte measurements or "points" were connected as dot plots to illustrate the trend in a manner similar to the format clinicians are familiar with viewing today (ie, a line graph).

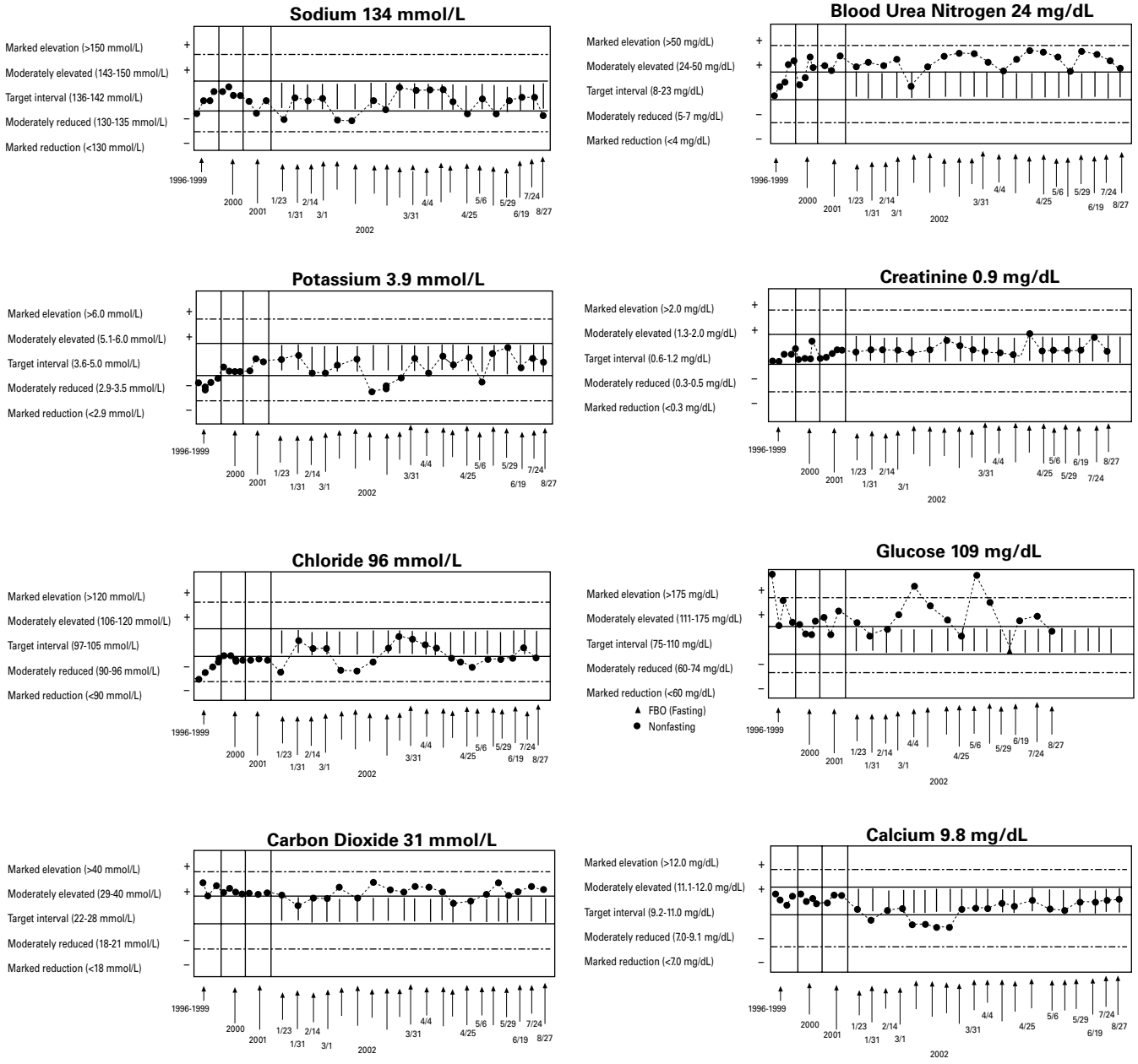

Figure 2 American Medical Association–designated basic metabolic panel (80048) graphic report. Values are given as Système International (SI) units for sodium, potassium, chloride, and carbon dioxide and as conventional units for blood urea nitrogen, creatinine, glucose, and calcium. To convert the values for sodium, potassium, chloride, and carbon dioxide to conventional (mEq/L), divide by 1.0; to convert the other values shown to SI units (mmol/L), multiply by the following conversion factors: blood urea nitrogen, 0.357; creatinine, 88.4; glucose, 0.05551; calcium, 0.25.

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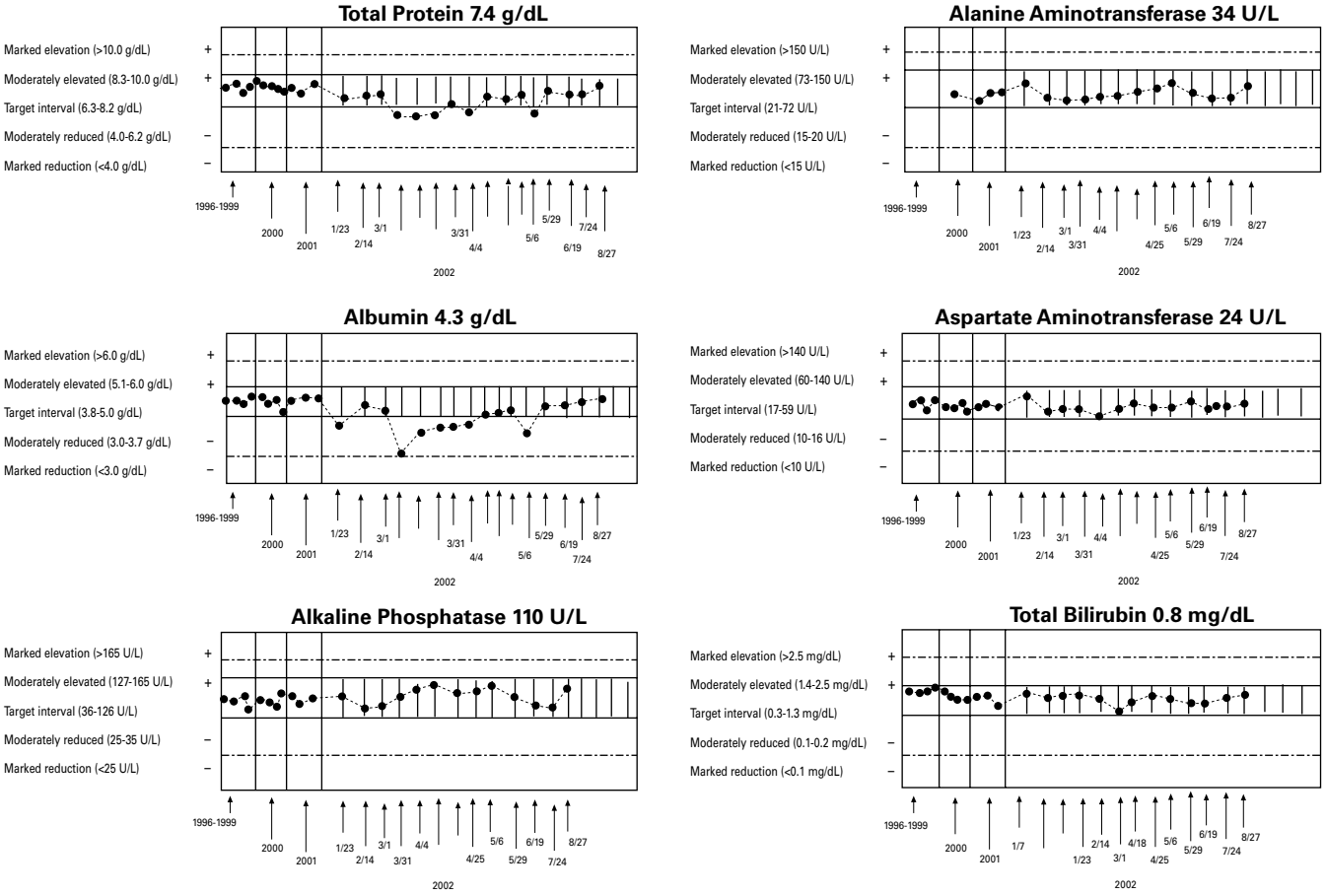

Figure 3 American Medical Association–designated hepatic function panel (80076) graphic report. Values given are conventional units. To convert to Système International units (g/L for total protein and albumin; μmol/L for total bilirubin; U/L for the other values), multiply by the following conversion factors: total protein and albumin, 10.0; total bilirubin, 17.1; other values, 1.0.

Results

Our prototype graphic display illustrating successive measurements of glucose and hemoglobin A_{1c} as a dot plot with its resulting trend is shown in Figure 1. The nonlinear, horizontal (ie, abscissa) time scale, highlighting specific dates of specimen collection, compresses data generated during a 7-year period on a single page that illustrates both recent and remote trends, with the vertical scale (ie, ordinate) incorporating scaled linear elevations and reductions in reference to a target interval for ease of interpretation and emphasis on abnormalities that enhance detection and reduce oversights. The most recent specimen measurement not only is indicated on the dot plot, but also is delineated further as a numeric value at the top of the graph, permitting facilitated recognition by clinicians. The single fasting blood glucose measurement taken on May 29, 2002, is brought to the attention of the reader both by the legend in the bottom left corner of the graph, as well as by the differently shaped dot point (ie, a triangular vs a circular dot point).

Figure 2 depicts 8 analytes comprising the AMA-designated 80046 Basic Metabolic Panel, with pronounced trend lines shown for each. The electrolyte values suggest a variable, minimal hypokalemic alkalosis, with elevations in blood urea nitrogen levels but normal creatinine measurements, most likely indicating dehydration, post–urinary tract obstruction status, or both.

The AMA-designated 80076 Hepatic Function Panel displayed in Figure 3 reflects variations in protein synthesis, but no evidence of drug-related hepatotoxic effects in enzyme alterations.

The lipid panel graph (AMA-designated 80061) permits concurrent assessment of 4 different lipids (cholesterol, high-density lipoprotein, low-density lipoprotein, and triglycerides); their ensuing trends over time are depicted in Figure 4, with statin therapy introduced in mid-2000, as indicated by a square in the graph itself and in the legend, showing a favorable impact on the levels of low-density lipoprotein and cholesterol.

Prostatic markers, as portrayed in Figure 5, provide corroboration of data by using trends to identify patients at risk for

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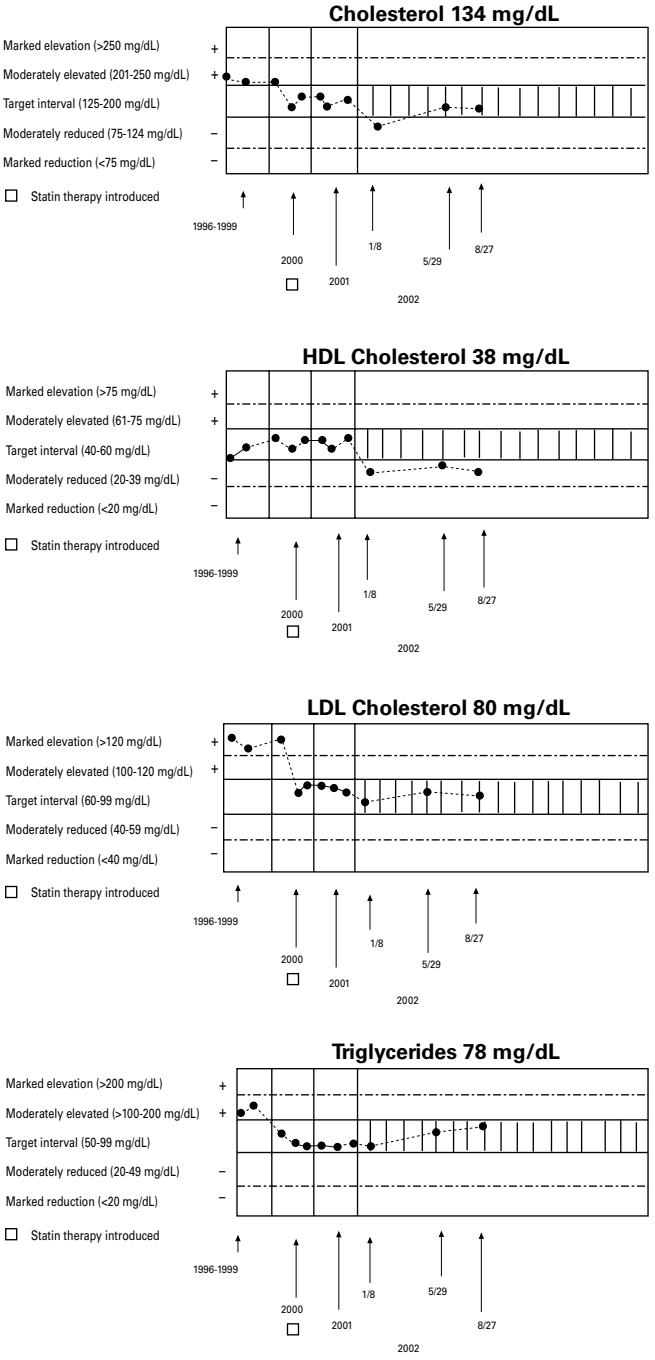

Figure 4 American Medical Association–designated lipid panel (80061) graphic report. Values given are conventional units. To convert to Système International units (mmol/L), multiply by the following conversion factors: cholesterol, 0.02586; triglycerides, 0.01129. HDL, high-density lipoprotein; LDL, low-density lipoprotein.

carcinoma, as well as to monitor therapy for nodular prostatic hyperplasia. Two drug therapies, tamsulosin (Flomax) and finasteride (Proscar), which were initiated in January 2002, also are depicted in Figure 5 by a triangle and a rectangle, respectively.

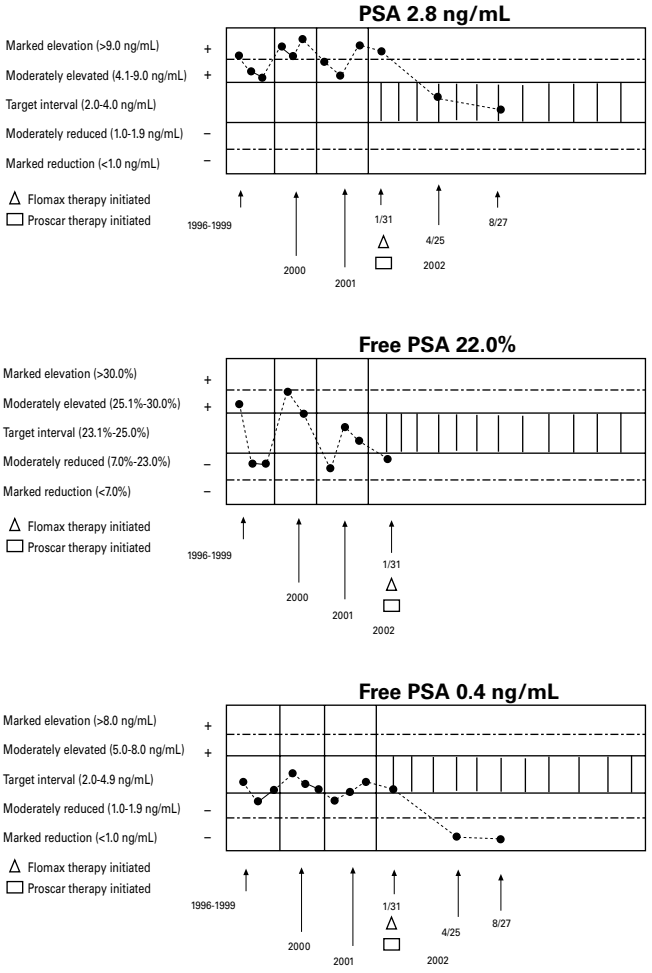

Figure 5 Prostatic markers graphic report. Conventional and Système International units are the same. PSA, prostate-specific antigen. Flomax is tamsulosin; Proscar, finasteride.

Last, the hemogram graphic display in Figure 6 shows the concordant trends for RBC count, hematocrit, and hemoglobin measurements consistent with anemia due to surgical blood loss and recovery over time.

The 6 aforementioned graphic displays consolidated more than a hundred pages of cumulative summary report results.

Discussion

More than a decade ago, Aller[9] highlighted the importance of improving our laboratory results reporting as the "end product of our efforts." He stated that the optimal format for chemistry and hematology results is as numeric data in compact trends, while microbiology and surgical pathology data necessitate a full page, textual display. Furthermore, he emphasized details to improve layout formats that not only are visually appealing, but also facilitate the interpretation of

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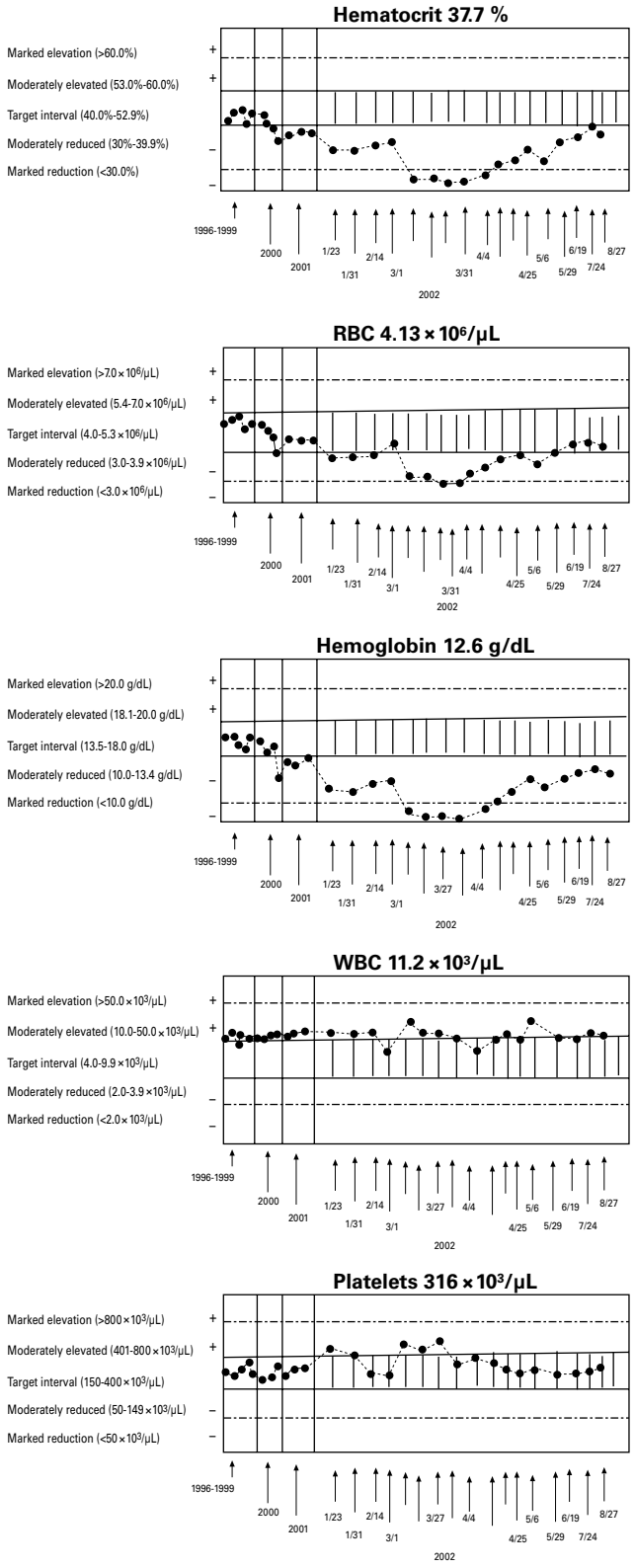

Figure 6 Hemogram panel graphic report. Values given are conventional units. To convert to Système International units (hematocrit, proportion of 1.0; RBC count, × 10^{12}/L; hemoglobin, g/L; WBC count, × 10^{9}/L; platelet count, × 10^{9}/L), multiply by the following factors: hematocrit, 0.01; RBC count, 1.0; hemoglobin, 10.0; WBC count, 0.001; platelet count, 1.0.

important clinical laboratory data while eliminating, or at least minimizing, nonessential data.[9]

Spackman and Beck[10] also emphasized the importance of effective communication in laboratory reports, both printed and computerized, with the need for improvements. We concur with their assessment that there is a substantial "risk of information overload" and that an inordinate amount of time is required for clinicians to review unimportant results for the most critical values amidst less relevant information. They also called attention to the need for well-organized and readable results, with easy-to-follow trends and highlighted critical values so that both the magnitude and direction of deviation are evident to the reader.[10]

In 1985, William Cleveland of AT & T Bell Laboratories described the elements of graphing data that are fundamental to our proposed results reporting of clinical pathology data.[11] He underscored the graphic perception of data displays and that graphs are ideal tools to analyze data with embedded information. Cleveland's dot plots illustrating the trend components of rate of change and the frequency of the points in relation to time resulting in the conveyance of a substantial amount of information about blood constituent's concentrations' quantitative variables seemed to be the most flexible and applicable for our own proposed clinical pathology data displays.

The display of such numeric data (ie, specimen measurements) graphically in a dot plot enhanced by the use of lines to connect the points generates a familiar line-type graph for trend identification, with deviations standing out for emphasis. Similar formats of graphic-based results reporting for different organ or disease panels provide familiarity for ease in reading and translating encoded information for more prompt and thorough perception and understanding. They also reflect not only pathogenesis, but also pathophysiology in a manner best fit for both display and interpretation. In addition, therapeutic intervention can be noted, to convey effectiveness of clinical management by detecting drug-related toxic effects in a hepatic function panel or the effectiveness of monitoring statin drug therapy in a lipid panel, for example.

In Cleveland's second work, visualization as the process in which information is encoded on graphic displays is deemed critical to data analysis of graphs.[12] In it, he further asserted that graphs are powerful tools provided that the information contained within can be decoded visually with relative ease[12]; this enables clinicians to examine graphs of data and, based on their experience, come to a more accurate and prompt conclusion.

Comprehensive, consolidated, graphic results reporting of a patient's clinical pathology laboratory data over an extended time, as highlighted in specific organ or disease panels, provides for more rapid access to and assimilation

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and integration of relevant information. More important, it permits the facilitation of clinical decisions without having to review large, bulky medical records for snapshot views of numeric hematologic, chemical, and immunologic clinical laboratory data. Such numeric data comprise approximately three fourths of clinical pathology results reporting in our experience, although individual patient population variations exist. In terms of our own laboratory last year, 73% of the clinical pathology data were numeric, with the breakdown in terms of billable procedures corresponding to 23% hematology and 45% chemistry, with immunology constituting the remaining 5% (M. Morris, MS, SH[ASCP], Manager, Department of Pathology, SUNY Medical University, Syracuse, written communication, September 5, 2002).

While medical records have continued to grow in thickness with their ever-increasing volumes of numeric information, their accessibility and usefulness has, in turn, diminished. A computer-based patient record incorporating innovative displays of clinical pathology laboratory data will greatly benefit both clinicians and consultants who have to peruse a medical record before visiting a patient. To do such in an efficient and comprehensive manner poses a challenge for today's medical record system, whose function is not only to support and improve the quality of patient care, but also to enhance the productivity of all health care professionals.

After consulting with colleagues in the field, we believe that programming the aforementioned examples of graphic-based reports should not be an obstacle to implementation; on the contrary, acceptance of change with appropriate behavior modifications may be the greatest challenge (R.P.C. Rodgers, MD, Clinical Specialty Consultant in Emerging Network Retrieval Protocols, National Library of Medicine, National Institutes of Health, written communication, July 26, 2002).

Conclusions

Clinical pathology data reports may be the single most important clinical pathology contribution to patient care by virtue of their enhancement of the efficiency, productivity, and effectiveness of clinicians in their roles in patient care. Numeric clinical pathology laboratory data lend themselves to graphic results reporting via the use of nonlinear time displays of dot plots as sequential, quantitative measurements that can be projected as trends over multiple years, with a vertical scale reflecting reference values, and from that, the magnitude of elevation or reduction of each measurement. Such graphic-based results reporting has the capability to be programmed into each clinical pathology laboratory's own laboratory information system.

In displays containing organ or disease panels consisting of multiple linked graphs, pathogenesis and pathophysiology may be ascertained; the resulting confirmation of each measurement concurrently by another determination benefits both clinicians and patients as perception of graphic results reports enhances analysis by highlighting trends and abnormal deviations of laboratory values.

The evolving computerized lifetime medical record necessitates a reduction in the thickness of current medical records with greater access to pertinent information and data. In the future, these records will be multimedia-based with the capability not only for text, but also for sound, video, and high-resolution images. Use of the graphic-based displays proposed would greatly reduce the number of pages of reports in the medical record and, hence, the thickness of the overall medical record with its present lack of access.

From the Department of Pathology, State University of New York Upstate Medical University, Syracuse.

Address reprint requests to Dr Henry: Dept of Pathology, State University of New York Upstate Medical University, 750 E Adams St, Syracuse, NY 13210.

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