AN ADAPTABLE SYSTEM FOR KEEPING INTAKE/OUTPUT RECORDS FOR FLUID MANAGEMENT IN THE CRITICALLY ILL*

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Medical information systems, even when useful in one setting, have not had widespread impact on medical practice, in part because they have not been easily transferable to other settings. Although hardware and software incompatibilities are frequently blamed, severe limitations on transference may be imposed by institutional, medical, and idiosyncratic requirements of different users. We have developed a computer-based system, with distinct advantages over manually-kept records, for keeping fluid volume, electrolyte, and nutritional balances for critically ill patients for use in a commercial patient monitoring system. Although the fundamental properties of and rationale for this fluid system are well defined, and all potential users have the same basic hardware and software, generalization of the system design to permit use in other settings has been time-consuming. This paper describes some features of the design, particularly its underlying table-driven structure, intended to facilitate transference.

Introduction

For patients with complex fluid management problems, traditional intake/output (I/O) records kept by nurses are frequently inadequate—they commonly contain errors, they reflect only fluid volumes and not their compositions, and they mask effects occurring over time periods longer than a day. For example, accumulative daily underreplacement of chloride in patients on nasogastric suction may go unrecognized until a metabolic alkalosis develops. Manual calculation of the cumulative chloride loss is so time consuming that it is done typically only after the alkalosis is manifest. The use of computer systems for I/O record keeping can reduce many of the problems of traditional nursing records.

The use of computer-based fluid volume tallies was described by Warner¹ in 1969; others²,³ have subsequently described systems for keeping summaries of administered electrolytes and nutrients in addition to fluid volumes. Siegel⁴ has developed a system for keeping sodium, potassium, chloride, and nitrogen balances and using them for estimating a patient's fluid, blood, electrolyte, and nutritional requirements based on the work of Moore⁵.

We have developed a computer system for keeping I/O records for use in a commercially available monitoring system, the Hewlett-Packard 5600A Patient Data Management System. The I/O system design has concentrated on provision of features permitting transfer to other institutions for use in caring for both adult and pediatric patients with a variety of acute clinical problems. Great emphasis has been placed on making the system sufficiently adaptable that it will be acceptable to nurses and physicians not participating directly in its development.

Rationale

To result in improved fluid management, an automated I/O system must fulfill two basic criteria as contrasted to present manual systems: it must be both usable and useful. The issue of usability relates to the design of the man/machine interface, which will be discussed later. We reasoned that the system would be more useful for fluid management if it added the following properties:

1. Increased accuracy in simple fluid volume balances: To assess the need for increased accuracy, we studied the I/O records of 30 randomly selected patients with intensive care unit (ICU) admissions lasting four or more days. Our hospital has multiple small ICUs (6 beds); records from five different ICUs were included in the sample. The study did not assess whether nurses read or recorded intake and output volumes accurately, since a computer system using manual entry by nurses would be

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subject to the same errors. Technicians familiar with the computer system were briefly instructed about I/O record keeping. They then used the nursing I/O records as a source for input to an early version of the automated I/O package. The nurses' and computer's records were then audited for accuracy by a physician and a senior medical student.

The few technician errors which occurred were attributable to inability to read the nurses' records. Nurses' records were without errors for only four of the thirty patients. Nursing records for thirty percent of all patient-days contained at least one error. Many records contained multiple errors--mistakes in addition, failure to include an entry in a total, adding an intake into an output subtotal, and even confusing a net intake of two liters for a net output. While addition errors can be limited through the use of calculators, they persisted in those units where calculators were used. These mistakes seemed to arise particularly from haste in the busy ICU setting, and, as expected, were more common in records for patients with many intakes and outputs. We concluded that the systematic storage and accurate arithmetic assured by an automated system were needed.

2. More complete information for fluid management: Since fluid intakes have known composition, and the composition of outputs can be measured or estimated, far more information is inherent than is reflected in manual records of I/O volumes. An automated system can provide detailed information about electrolyte balance and nutritional intake.

3. The ability to manipulate and display data in a variety of ways without manual recrashing: Manually-kept records are typically oriented towards a 24-hour period. Events occurring over the course of days may be overlooked. Once data have been entered into a computer, however, the calculation of accumulated balances can be done without additional nursing effort. Data can, moreover, be displayed in various tabular or graphical formats. A computer system can create a graph, for example, of the trend of the accumulated sodium balance over time, again without additional user effort.

Design Philosophy

The system design philosophy had three main precepts:

1. For medical information systems to have more than isolated impact, they must be developed in collaboration with industry. We planned the I/O system to be built using hardware and software used by multiple institutions. We have used the Hewlett-Packard system, which uses 16-key keypads or full ASCII keyboards for input with video monitors or ASCII terminals for displays. Higher level language support for this system is at present limited to FORTRAN.

2. The system should be acceptable to physicians and nurses with diverse backgrounds, experience, and specialties. Despite agreement among potential users on the medical rationale for the system, these users differed significantly on its proposed operational details. These differences can be classified as:

   a) Institutional: The system had to accommodate a variety of IV solutions and blood products that are used in different clinical settings. Even the definition of the start of a "day" for accumulating fluid totals had to be possible; at our hospital, a day lasts from 6:01 a.m. one day until 6 a.m. the next; other hospitals use different schedules.

   b) Medical: The system's acceptability, and hence its underlying design, depends on its intended clinical setting. Uses with various patient populations--neonatal, pediatric, trauma, burn, respiratory, and cardiac surgical--require a system that can be tailored to the particular clinical environment.

   c) Idiosyncratic: Human foibles, or preferences, account for many differences suggested by potential users. These differences almost never affect the underlying system structure, but require facilities at the user interface. Some users, for example, prefer data to be displayed in a horizontal format while others prefer a vertical format. Such issues, while seemingly inconsequential, are crucial for acceptance. Further, the provision of facilities for accommodating them may be extremely time-consuming.

3. The system should be easy for nurses to use. It should not require them to relearn all recording. For example, the design of the data entry display form should resemble the layout of currently used I/O flow sheets. In addition, the system should provide a way for new users, who may not have had extensive training in the use of the system, to know how to proceed at any step.

System Structure

Our approach to the problem of transferability has been to design the I/O system with the following features:

1. It is self-instructional.

2. It merges the traditionally separate concepts of data entry and review.

3. It is table-driven. The use of tables provides users with choice of both the constituents (e.g., sodium, potassium, protein) that the system tallies and the types of fluids (e.g., normal saline, D5W) that will be listed.
4. Users may define the formats and contents of reports. The report generator automatically retrieves necessary information from the system's files as the report is produced.

The underlying structure of the system is designed as a series of user-configurable tables. At the most fundamental level, users may specify the fluid components that the system will tally; that is, they may define the basic building blocks of fluids and additives. Most users will probably choose a default set including electrolytes—sodium, potassium, chloride—and nutritional elements—protein, carbohydrates, and calories. Potential users could not agree, however, on all components. Some wanted to distinguish orally given calories from intravenous; others wanted to keep nitrogen balances; still others wanted to keep track of certain drugs. By making the constituents user-definable, the system can be tailored to their particular requirements. Further, because the constituents may be altered, the system can evolve without reprogramming as medical practice changes and additional information becomes important for fluid management.

Once users have configured the table of fluid constituents, they may then define a second table of the commonly occurring intakes, outputs, and additives for their clinical settings. Normal saline, for example, would be defined as 154 mEq of both sodium and chloride in a liter of water. As new fluids come into use, or old fall into disuse, they may be easily added to or deleted from the system. An example of the fluids configured for our hospital is shown in Fig. 1.

Not every fluid given to or output from a patient can have all of its components pre-specified—a system of definition of individual fluids is also required. Hyperalimentation solutions, for example, have a variable composition depending on a patient's requirements. The possible combinations are too numerous to be listed exhaustively. For this reason, users may define the composition of non-standard solutions—IV admixtures or oral fluid dilutions—using a facility that will be described. Similarly, outputs such as urine have variable compositions that are known only after they are measured in a laboratory. Therefore, the system has been provided with a capability for specifying their composition once it is known.

An implication of the capability to configure fluid components is that the reports must also be configurable—if nitrogen balances are tallied, the user must be able to obtain them on a report. Therefore, a special report generator has been developed so that users may specify the content and formats of various video and printed outputs. With the text editor provided by the manufacturer, users may define reports with a command language interpreted at run time, permitting the reports to be modified quickly and easily. Reports may use horizontal or vertical formats, consist of multiple pages, and be paged forward.
FLUID ENTRY

1 ID# 1111 DOE JOHN
2 TIME 1000 1 SEP
3 WEIGHT (KG) 60.00 AT 0900

99 STORE ENTRY

FOR INSTRUCTIONS PUSH 'I: GO'
ENTRY : PAGE 1 OF 1

FIG. 3: The basic display used for nursing entry of fluid volumes. Nurses select the fluids appropriate for each patient.

TEST DOE JOHN 01 SEP 1004
FREAMINE 2 +ADD* 2 - ADDITIVE SELECTION

<table>
<thead>
<tr>
<th>ADDITIVE</th>
<th>AMT</th>
<th>U/L</th>
<th>COMP</th>
<th>STD</th>
<th>TOT</th>
<th>U/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 IV H2O</td>
<td>0 MLS</td>
<td>VOL</td>
<td>500 1000 MLS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 ORAL H2O</td>
<td>0 MLS</td>
<td>NA</td>
<td>10 55 MEQ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 D50/W</td>
<td>500 MLS K</td>
<td>0 0 MEQ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 DI0/W</td>
<td>0 MLS</td>
<td>CA</td>
<td>0 0 MEQ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 ACL</td>
<td>0 MEQ MG</td>
<td>0 0 MEQ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 AACL</td>
<td>0 MEQ CL</td>
<td>0 0 MEQ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 KCL</td>
<td>0 MEQ HCO3</td>
<td>0 0 MEQ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 CA GLUCON</td>
<td>0 MEQ HP04</td>
<td>28 10 MEQ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 CA GLUCON</td>
<td>0 GMS</td>
<td>SO4</td>
<td>0 0 MEQ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 K ACETATE</td>
<td>0 MEQ BASE</td>
<td>0 0 MEQ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 MGO4</td>
<td>0 MEQ</td>
<td>HGB</td>
<td>0 0 GM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 MGO4</td>
<td>0 GMS</td>
<td>CAL</td>
<td>0 850 CAL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 CACL2</td>
<td>0 MEQ PROT</td>
<td>78 39 GM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 CACL2</td>
<td>0 GMS</td>
<td>NTR</td>
<td>0 0 GM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>99 'I: GO' TO STORE</td>
<td>CARB</td>
<td>0 250 GM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FOR INSTRUCTIONS PUSH 'I: GO'
ENTRY : PAGE 1 OF 1

FIG. 4: An example of the definition of a hyperalimentation solution. The volumes of additives are specified on the left and the composition of the resultant solution is listed on the right.

or backward in time to permit review of the entire admission. An example of a page of a report is illustrated in Fig. 2.

Operation of the System

An important design feature is illustrated in Fig. 3. When nurses make written entries in a chart, they can immediately see the previous entry and note a significant difference from their current one. We have incorporated this useful clinical monitor in the automated system. A patient's current intakes and outputs are listed vertically on the left margin. At the time of an hour's entry, the three prior hours' entries are retrieved and displayed. The concept of blending data entry and review permits nurses to validate both old and new data, much as they can with traditional charting. This feature should lead to reduction in errors and enhance acceptance by users.

If a fluid being given to a patient is not on his current list of fluids, a nurse may add it from the master fluid list, shown in Fig. 1. If the new fluid is non-standard, such as a hyperalimentation solution, then a display as shown in Fig. 4 is generated. In this display, the solution to be modified is listed at the top, the possible additives are listed along the left margin, and the additives are chosen, the components of the resulting solution--base solution plus additives--are listed on the right half of the display. The additives may be IV solutions, salts, or drugs. In the example shown, the admixture is composed of equal parts (500 ml each) of Freamine II and D50 W, with added sodium and potassium chloride. The mechanism permits the nurse to specify the composition of non-standard fluids quickly without typing in additive names. Nurses need only select the proper additive from the list and specify its quantity.

When the nurse has entered the volume of each of a patient's current intakes and outputs and indicates that the data are to be stored, the system multiplies the volume of each fluid times its tabled constituents. These totals are added to running sums stored for each nursing shift, day, and duration of the ICU admission. These values are used by the report generator.

Discussion

Friedman and Gustafson, in attempting to account for the lack of impact of computers in clinical medicine, pointed out that applications have not been easily transferred from one institution to another. They accounted for this lack of transference by crediting the disorganized array of computer languages and computer systems used for medical applications. While these hardware and software incompatibilities may be formidable, they account for only part of the problem. In our case, all potential users employ the same basic hardware and software and want the basic capabilities of the I/O system, but personal, medical, and institutional dif-

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ferences hinder its transference to and acceptance in another setting.

The I/O system has been through a sequence of developmental and testing stages for the last two years and is currently being distributed nationally. While two years might seem a long time for a system whose fundamental medical concepts have been known from the outset, virtually the entire developmental cycle has been spent adding degrees of generality so that the system could be adapted to other settings. At one stage, for example, all reports and all fluid constituents were hard-coded instead of configurable. In retrospect, the developmental cycle might have been shortened if the initial design had been totally configurable; however, this is a moot point since only after building the specifics were we able to determine the elements to generalize.

The development of the I/O system has made us realize the importance of some fundamental software resources for creating adaptable medical information systems. The use of FORTRAN, with its limited data structures, prolonged the implementation of the underlying table-driven design. Secondly the report generator, developed specifically for this project, is a fundamental functional element required for many applications in a patient information system. To enhance the basic system capability, a generalized version of the report generator is currently being written.

References


