Computer-Assisted Compounding of Neonatal/ Pediatric Parenteral Nutrition Solutions

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ABSTRACT

A computer software package was developed to perform the calculations involved in compounding neonatal/pediatric parenteral nutrition (PN) solutions. A 16-bit microcomputer was used to develop and evaluate the software. The program requires a minimum of user input and is menu-driven. It performs the calculations, prints appropriate labels, a preparation card and a summary of the nutritional content of the solution. Error check routines and a check for calcium-phosphate compatibility are imbedded in the program.

The effect of the package on PN compounding was evaluated using a computer model. The evaluation indicated the computer-assisted system was more efficient than a manual system and the possibility of computational error was reduced. The increase in efficiency with the computer-assisted system was between 12-15% compared to a manual system. Computer modeling appeared to be a useful tool in both evaluating the software package and determining the effect it would have on work flow.

Key Words: *parenteral nutrition, computers, computer program*

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RÉSUMÉ

Un logiciel fut développé afin d'effectuer les calculs nécessaires pour l'alimentation parentérale en néonatologie et pédiatrie. Un micro ordinateur de 16 bits fut utilisé pour développer et évaluer le logiciel. Ce programme est contrôlé par un menu principal et demande que très peu d'entrée de données de l'utilisateur. Le programme exécute les calculs et imprime les étiquettes appropriées, il imprime également une carte de préparation et un sommaire de la solution du contenu nutritionnel. Les vérifications d'erreurs routinières et les incompatibilités phosphate/calcium sont incorporées dans ce programme.

Un ordinateur fut utilisé comme outil pour évaluer l'effet du logiciel de composé d'AP. L'évaluation a démontré que le système supporté de l'ordinateur était plus efficace que le système manuel. La possibilité de commettre des erreurs est donc réduite. L'efficacité du système d'ordinateur s'élève donc entre 12 et 15 pour cent si on le compare au système manuel. Le fait d'avoir utilisé l'ordinateur comme outil pour évaluer le logiciel et de déterminer ses effets sur le déroulement du travail, semble avoir été un bon instrument.

Mots clés: *alimentation parentérale, logiciel, ordinateur*

INTRODUCTION

Over the past few years, financial pressures have motivated hospital pharmacists to examine current technology as a major means of increasing efficiency.[1,2] One area which has received some attention is the computerization of parenteral nutrition (PN) calculations.[3,4,5,6] Although the manual calculations involved are not difficult, they are time consuming and a current report indicates that about 17% of the calculations done by pharmacists are subject to interruption which can lead to errors.[6] In response to this problem and in an attempt to increase productivity, a computer software package was developed to perform the calculations involved in preparing neonatal/pediatric PN solutions.

System Description

Hardware:

The program modules were developed using an 80286 16 bit microcomputer (Computer Systems, Toronto, Ontario), with 640 kilobyte random-access memory (RAM) and 30 megabyte hard drive although the software performs well on any IBM-compatable machine with at least 512 kilobyte RAM. A hard drive is strongly recommended for data base management and a dot-matrix printer is required for label, preparation card and nutritional summary printing. A variety of different printers are supported by the system.

Interfacing to other software systems can be achieved through file-sharing and the entire system

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was designed to eventually be interfaced to a peristaltic pump mixing device.

Software:
The software package is designed to require a minimum of user input and only the information presented on the PN requisition needs to be entered into the computer. Menu selection is used to make data entry and editing as simple as possible. The system performs all the calculations and generates a preparation card which lists the additives and the quantity of each which is needed for the solution preparation.

A check for calcium/phosphate compatibility is performed and based on this check, a single container is used or the solution is prepared in two containers to separate the phosphate from the calcium and magnesium salts. Appropriate labels are generated for the final containers and a summary of the nutritional content of the solution is printed and compared to the usual nutritional requirements.

The input data is saved to a file for future reference and can be recalled and edited for patients whose treatment is being continued. This data base can also be used for charging, inventory control, workload measurement, utilization review or as an interface to other software systems. A degree of flexibility is achieved through a setup menu which allows the user to modify some aspects of the software.

The software is designed in a modular fashion and the program modules were written in Microsoft QuickC (Microsoft Corp. Redmond WA). This language was selected due to its efficiency for procedural applications and speed of execution. Since C is a medium-level language it requires more lines of code than most other languages but its advantages offset this drawback.

The software system is composed of a series of modules each of which performs a specific function. Descriptions of the major modules can be found in Appendix I.

SOFTWARE EVALUATION

In order to evaluate the software, 25 neonatal/pediatric PN orders were selected at random using old orders from the previous six months. Each order was processed both manually, using a calculator and a typewriter, and then using the computer. For each order the calculations were performed, a preparation card made and appropriate labels were prepared. The times required for each task were determined using a stopwatch and the number of errors found were recorded. The two sets of time values were compared using students t-test for grouped data. All testing was done using pharmacists experienced in PN solution preparation.

In order to assess the impact of the computer on PN preparation, a computer model was developed. The specific tasks involved in the preparation and the individuals responsible for each task were identified and then twenty five occurrences of each task were observed in the pharmacy IV area and the time required for each task was recorded. These data are presented in Table I. For the computer model, the tasks were arranged in order of occurrence and for each run of the simulation, the time required for each task was assigned by the computer. The time assigned was determined through an algorithm which randomly selected a value based on the observed mean and standard deviation for each task. The time values for each task were assumed to follow a normal distribution.

Table I: PN preparation tasks and times

Computerized System		
Task	**Staff**	**Time***
1. Triage order	Pharmacist	240 (85)
2. Enter order into computer	Technician I	45 (15)
3. Check calculations	Pharmacist	240 (85)
4. Set up preparation tray	Technician I	150 (43)
5. Prepare mixture	Technician II	750 (212)
6. Check solution volumes	Pharmacist	45 (10)
7. Check mixture and label	Pharmacist	45 (10)
8. Package order for delivery	Technician I	120 (75)
Manual System		
Task	**Staff**	**Time***
1. Triage order	Pharmacist	240 (85)
2. Perform calculations	Pharmacist	356 (114)
3. Check calculations	Pharmacist	240 (85)
4. Type prep card / labels	Technician I	200 (15)
5. Set up preparation tray	Technician I	150 (43)
6. Prepare mixture	Technician II	750 (212)
7. Check solution volumes	Pharmacist	45 (10)
8. Check mixture and label	Pharmacist	45 (10)
9. Package order for delivery	Technician I	120 (75)

* Mean time in seconds with standard deviation in parenthesis.

The staffing for the model consisted of one pharmacist and two pharmacy technicians designated Technician I and Technician II. While a staff member was occupied with a task, a flag was set and in this way the amount of busy and idle time for each person was followed. A series of queues were generated representing each task and as a given task for an order was completed, the order was passed to the next queue. When the individual responsible for performing the task was free, the first order in the queue was assigned to that individual who remained occupied until the time assigned for that task had elapsed. The entire model was controlled by a computer-generated clock which allowed the status of each order and the activity of each staff member to be evaluated at one second intervals.

Problems which required pharmacist intervention, such as telephoning the prescribing physician for order clarification or revision, were simulated by providing random interruptions. These interruptions occurred with a one in ten probability for a given order and lasted for a mean of 180 seconds with a standard deviation of 70. These values were determined by interviewing pharmacists and collecting ten estimates of how long a typical interruption would last and how frequently they occur. The major source of pharmacist interuption occurred when the Technician II required a check of the additive volumes drawn up. This was simulated by having the current pharmacist activity suspended while this check was done then having the activity resume after the check was complete.

When all the orders had been processed and placed in the last queue, a report was generated which detailed the time required for each task in each order, the total time required to process each order and the amount of idle and work time tracked for each staff member.

RESULTS

The results of the time required to complete the 25 randomly selected neonatal/pediatric PN orders by pharmacists and computers are presented in Table II. The results of the system evaluation using the computer model are presented in Tables III and IV. Where appropriate, students t-test for grouped data was used to determine whether values were statistically different.

DISCUSSION

The results of the system evaluation indicated that the use of computer-assisted calculations had a number of positive effects on the preparation of neonatal/pediatric PN solutions. The time required for the calculations was considerably reduced using the computer although the use of computer modeling techniques showed that the magnitude of the overall time saving depended on the staffing pattern used and the number of orders being processed. The efficiency of the computerized system was maximized if all the orders were present in the pharmacy prior to

Table II: Calculation times

System	Mean (Sec)	Std Dev	Calculation Errors
Manual	356	114	4
Computer	45	15	0
Difference significant $p<0.01$			n=25

Table III: Total time required for PN preparation

Number of Orders	Total Preparation Time* Computer System	Total Preparation Time* Manual System	Time Saved (min)†	Increased‡ Efficiency (%)
1.	36.41 (3.87)	42.62 (5.01)	6.21	14.57
2.	51.56 (4.12)	55.39 (5.94)	3.83	6.91
3.	66.59 (2.17)	73.27 (7.35)	6.68	10.44
4.	81.39 (2.96)	91.80 (4.94)	10.41	11.88
5.	95.59 (2.23)	111.04 (7.24)	15.45	14.17
6.	106.46 (4.99)	123.03 (4.84)	16.57	13.47
7.	121.27 (6.00)	140.34 (6.52)	19.07	13.59
8.	133.03 (7.05)	156.22 (6.96)	23.19	14.84
9.	147.54 (7.75)	169.82 (7.94)	22.28	13.12
10.	160.81 (8.55)	186.22 (10.03)	25.41	13.65

* Time in minutes with standard deviation in parenthesis. All comparisons of total time required between manual and computerized methods are significantly different, except number of orders = 2.
† Manual system — computerized system (Mean times).
‡ (Time saved / time for manual system) x 100.

Table IV: Staff idle time

	Computer*	Manual*	
Pharmacist	35.98 (5.47)	11.27 (1.78)	$p<0.01$
Technician I	67.26 (11.81)	56.51 (2.32)	$p<0.01$
Technician II	13.28 (2.58)	30.93 (7.03)	$p<0.01$

* Expressed as % of total preparation time with standard deviation in parenthesis.

starting the processing and if the number of orders exceeded three.

The incidence of computational errors was higher with the manual system and although all of the errors were detected and corrected through the checking procedure, the fact that they occurred at all suggests a possibility that some may miss detection. The error rate with manual calculations was about 16% while no errors were detected using the computer system.

Use of the computer model also established that extrapolation of the time saved in one task to all the orders being processed may overstate the total time saved. Usually more than one individual is involved in the preparation of PN solutions and the length of time required for each task varies with each order. The tasks also have an inherent hierarchy where some tasks must be completed before the next can be started. The interactions between tasks and time can, therefore, become quite complex and are better described using a computer model rather than assuming more simple direct linear relationships.

A major advantage of the computerized system was the increase in pharmacist idle time. This allows the pharmacist to be available to deal with problems and non-routine situations. The pharmacist is able to solve these problems and the other members of the work team are not delayed by having to wait for the pharmacist.

The overall increase in efficiency for neonatal/pediatric PN preparation using the computerized system may be expected to be from 12 to 15% based on the data generated by the computer model.

CONCLUSIONS

The use of a computer to assist in PN calculations leads to an overall increase in efficiency and a reduced possibility of computational error. Task redistribution and an increase in pharmacist idle time should lead to a smoother work flow which is less subject to disruption when the pharmacist is engaged in solving problems.

The computer software package described should allow an increase in productivity of about 12-15% and reduce the possibility of computational error in preparing PN solutions.

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Appendix I: Program Modules

Data Entry Module:
When PN therapy is started for a patient, the following information must be entered into the computer:

1. Patient name
2. Ward
3. Physician name
4. Patient identification number
5. Patient weight
6. Pharmacist initials
7. Rate of administration

A screen is presented and the user is prompted for the information through high-lighted blocks. After this, a screen is presented which prompts the user for the solution components. The input is the quantity ordered per 24 hours which are the values the physician has entered on the requisition. In this way there is no pre-calculation required rather, simple transcription of the information from the requisition to the computer. Numerical options are selected for the specific salt to be used; for sodium and potassium either the chloride or acetate may be selected and for calcium the chloride, gluconate or gluceptate may be selected. This selection is useful when solution compatibility problems exist or when the patient has acid/base imbalances. As well as the base and electrolyte components, the user is prompted for trace metals, vitamins, and insulin. The selection of the phosphate salt, either sodium, potassium or a combination is done by the computer.

At this point, the user has the option of reviewing and editing any of the information entered. This option involves an on-screen editor which displays the information entered. Any items to be changed are selected then modified and re-displayed for verification. For subsequent PN orders, this feature allows the file data to be entered directly into the editor and the only user input required is the patient identification number. The data can then be modified as required for the current order.

Calculation Module:
Once the patient and order information has been entered, the calculations needed for the preparation card are done by the computer. The first calculation involves the quantity and type of phosphate salt to be used. The computer will elect to use either the sodium, potassium or a combination of salts depending on the array of electrolytes ordered. Following this, the volume of sodium, potassium, magnesium and calcium additives required are determined and the volumes of trace metals, vitamins and insulin are calculated. The total volume is determined from the rate of administration of the base solution and the volumes of the additives are considered in calculating the water content of the solution. Since some solution will be lost in the IV lines and associated administration apparatus, an excess of solution may be prepared. The amount of this coverage is predetermined by the user through a setup menu.

The end product of the calculation module is a listing of the volumes of each component required to prepare the solution ordered.

Error Check Module:
During the calculation process, a number of error flags may be set. For example, if the quantity of phosphorus ordered exceeds the maximum allowable due to the amounts of sodium and potassium ordered, an error flag is set. If the amount of a component ordered is less than the inherent amount present in the amino acid solution or trace metal injection used, another flag is set. At the conclusion of the calculation routine, the error flags are examined and appropriate messages are displayed on the screen describing what the problem is and suggesting appropriate measures to rectify the problem. Any errors at this time are fatal to the system and program execution is aborted to ensure that the problem is discussed with the ordering physician and a revised order is issued.

Compatibility Check Module:
A significant problem in compounding PN solutions, particularly neonatal/pediatric solutions due to the high content of both calcium and phosphorous, is the formation of insoluble calcium phosphate.[7] This is essentially a problem involving temperature, component concentration and solution pH. This problem could be managed within limits, by controlling the pH of the final solution. This fact has been recognized and has been addressed in several publications where the pH of PN solutions were lowered by the inclusion of cysteine HCl.[8,9]

A number of studies have been conducted examining the quantities of calcium and phosphorous which are compatible for a given base solution.[8,9,10,11] Generally these data have been presented as curves which can be used as an empirical guide for solution compounding. The values presented in these papers were used and an algorithm developed using non-linear regression to allow the computer to determine whether a compatibility problem exists. The algorithm is biased so that if the result is uncertain, the mixture is considered incompatible.

If the computer determines that the mixture is incompatible, a screen is presented which informs the user of the problem and suggests a calcium/phosphorus content which is compatible. The user is given the option of aborting the program and obtaining a revised order or continuing the preparation but the total solution will be split into two containers with the phosphate being separate from the magnesium and calcium. Although this precludes the compatibility problem, it introduces difficulties in the administration since the solutions must be given on an alternating basis over the course of the day or through two IV lines.[10]

A recent publication has suggested that the formation of insoluble calcium phosphate in PN solutions may have serious clinical implications.[11] These authors describe a case of pulmonary deposition of insoluble crystals causing a granulomatous interstitial pneumonitis and this finding emphasizes the need for even greater vigilance in detecting and avoiding this incompatibility.

Printing Module:
The output of the program consists of three forms which are printed on 10 x 9.5 cm labels. The printing of these can be suspended at any time by pressing the function key (F1) and the printing routine is restarted at the beginning. This allows realignment of the labels should printing be started at an inappropriate part of the label.

The first output is a label for the final container and indicates the content of each additive in the bag. The current date for the output is taken from the internal clock in the computer and the expiry date is calculated by the computer. If more than one container is required, two labels are prepared.

The second element to be printed is the label for the preparation card. This is designed to be used in the preparation of the solution and lists the components to be used and the volumes required. Usually this label is affixed to an index file card and is used to set up a tray containing the components to be used in the preparation and then used as a formula card by the individual actually preparing the solution.

The final element to be printed is a summary of the nutritional content of the solution. These values are presented on the basis of quantity administered per Kg of weight per 24 hours. These values are compared to the usual quantities required and provide a check on the appropriateness of the solution.

Filing Module:
The final module of the program files the information on the disk for future reference and the user is returned to the main menu.