Development of an Affordable Data Collection, Reporting, and Analysis System

William R Howard MBA RRT

Available professionally designed systems for recording, storing, retrieving, and analyzing patient data (such as treatments delivered, laboratory and pulmonary function test results, ventilator settings, and patient assessments) are prohibitively expensive to many hospitals and clinics. At Tufts-New England Medical Center we designed and implemented a computerized patient data management system that uses relatively inexpensive "personal digital assistants" and inexpensive, commonly-available software. Compared to the pen-and-paper flow sheet system we previously used, our computerized system saves time and money, is accurate and user-friendly, and allows data retrieval and analysis that can improve clinical practice and efficiency. We believe our experience could benefit other institutions. *Key words: data collection, personal digital assistant, database, management information system.* [Respir Care 2003;48(2):131–137]

Introduction

The charting of ventilator settings, measured values, patient assessment, administered treatments, and progress notes is a requirement of our profession. Charting is usually done with paper flow sheets. At Tufts-New England Medical Center, these forms are collected daily and become a data resource to analyze clinical practice and conduct quality assurance analysis. Annually, approximately 30,000 forms are generated to record this information. To decrease the amount of paper generated we developed an electronic alternative to manual data collection. There are no professional guidelines for capturing data electronically, and we considered it reasonable to extrapolate the manual-entry flow sheet recording that we have used and incorporate it into an electronic system.

Few respiratory care departments can afford professionally designed and maintained systems such as Clinivision (Mallinckrodt, Carlsbad, California), Tenet (Sandy, Utah), or MediServe (Tempe, Arizona), which fulfill data collection, reporting needs, and more. Following the development of new software for hand-held microcomputers known as "personal digital assistants" (PDAs), we developed an affordable system that allows many more respiratory therapists the ability to electronically capture, store, chart, and analyze data that previously was entered on flow paper sheets. This article describes the Electronic Data Capture Project at Tufts-New England Medical Center.

The use of PDAs has entered the health care arena, and it seems logical that the respiratory care profession employ PDA technology. Many medical applications for PDAs have been developed,[1–7] yet these have used PDAs primarily as tools for accessing point-of-care literature, drug referencing, critical care formula calculation, and drug dosage.

Professionally developed data management systems for respiratory care are cost-prohibitive for most managers. Requests for proposals at Tufts-New England Medical Center (a 400-bed institution) ranged from $150,000 to $250,000, depending on system features. With our desire to manage data more efficiently, we developed a system that downloads PDA-captured information to a central database for storage, reporting, and analysis. The system requires:

- Palm M-130 PDAs (Palm, Santa Clara, California)
- SmartList to Go software (DataViz, Milford, Connecticut)
- Microsoft Access software (Microsoft Corporation, Redmond, Washington)
- Desktop computer with Windows operating system (Microsoft Corporation, Redmond, Washington)
- Laser printer

William R Howard MBA RRT is affiliated with the Department of Respiratory Care, Tufts-New England Medical Center, Boston, Massachusetts.

Correspondence: William R Howard MBA RRT, Department of Respiratory Care, Tufts-New England Medical Center, 750 Washington Street, T-NEMC #785, Boston MA 02111. E-mail: whoward@lifespan.org.

Fig. 1. Palm M-130 personal digital assistant (hand-held) used for point-of-care data collection.

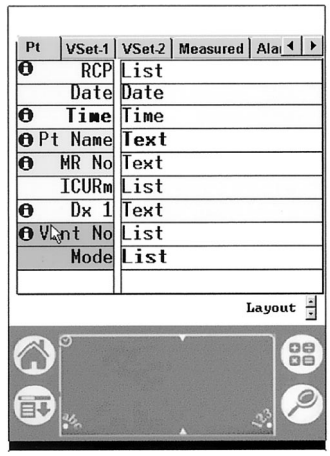


Fig. 2. Record entry screen of the Palm M-130 personal digital assistant, showing the first tab of fields: Pt = patient, VSet-1 = ventilator setting 1, VSet-2 = ventilator setting 2, and Measured (values for peak airway pressure, respiratory frequency, inspiratory-expiratory ratio, etc). The field labels are used interchangeably with various ventilator brands. RCP = name of respiratory therapist entering the data. Pt = patient name. MR = medical record. ICURm = intensive care unit and room number. Dx 1 = diagnosis 1. Vent = ventilator. Mode = ventilator mode.

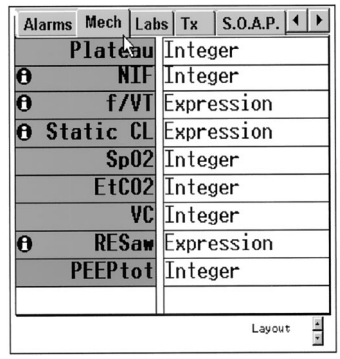


Fig. 3. Record entry screen of the Palm M-130 personal digital assistant, showing the fields labeled Alarms, Mechanics, Labs (laboratory results), Tx (treatments), and S.O.A.P. (subjective, objective, assessment, plan). The field labels are used interchangeably with various ventilator brands. Plateau = plateau pressure. NIF = negative inspiratory force. f/V_T = respiratory frequency divided by tidal volume. CL = compliance. [S_{pO_2}] = blood oxygen saturation measured via pulse oximetry. EtCO2 = end-tidal carbon dioxide pressure. VC = vital capacity. RESaw = airway resistance. PEEPtot = total positive end-expiratory pressure.

The Palm M-130 PDA (Fig. 1) was chosen because it offers:

- Built-in long-life rechargeable lithium battery
- Pocket size (dimensions 12.2 × 7.8 × 2.2 cm, weight 153 g)
- Durable hard plastic case
- Reasonably low price ($249 retail)
- Contrasting and sharp color detail
- Large record storage
- Intuitive, easy-to-learn user interface

The SmartList To Go application stores the patient data on the PDA. A single database was designed, with 2 primary tables: one for adult and pediatric patients and another for neonates.

The principle feature of SmartList To Go is customization, which allows for:

- Custom field labels, font and color for each label and field, constant labels, pop-up help, resizable labels/field column for each tab, and display field in multiple places
- Drag-and-drop fields in the form designer
- List view scrolls horizontally to support up to 80 fields
- Conditional expressions
- Ability to create a database start-up screen
- Individual auto-writer for text, memorandum, and numeric fields
- Increment/decrement control of numeric fields
- Automatic calculation of certain fields

Data Entry Process

We programmed the SmartList To Go software to show a total of 9 data entry screens (Figs. 2 and 3) for the adult/pediatric database and 8 data entry screens for the neonatal database. The screens are displayed by selecting a tab at the top of the SmartList To Go software template. When the desired tab is selected, the display lists several preprogrammed fields in which to enter clinical data. A total of 80 fields are available for each patient record (Table 1).

Aside from manual entry of the patient's name and medical record number in the first tab, the PDA system allows the programmer to profile the fields as drop-down menus from which the clinician can choose items to fill in the

Table 1. Data Entry Tabs and Fields

Tab	Fields	Clinician Interface
Pt (patient) (see Fig. 2)	Respiratory therapist (list) Date Time Patient name (manual entry)	In each field, drop-down lists are presented, from which the clinician can select the appropriate entry. A built-in calendar and clock enter the date and precise time.
	Medical record number (manual entry)	Medical record number is a manual stylus entry, which is done with either a keyboard or the "graffiti" function.
	Intensive care unit and room number (list) Diagnosis (list) Ventilator and number (list) Mode (list)	Diagnosis is entered from either drop-down lists or manual entry, using the built-in keyboard or stand-alone keyboard.
Ventilator Settings-1	V_T (tidal volume)*† RR (respiratory rate)* F_{IO_2} (fraction of inspired oxygen)* PEEP/AMP (positive end-expiratory pressure/amplitude)* Trigger method*‡ Trigger sensitivity* PFR (peak flow rate)* PSV (pressure-support ventilation)*† TC (time constant)*† ESens% (expiratory sensitivity)*†	These are either drop-down list selections or numeric entries. Numeric entries can be manually entered or entered using the increment-up/down arrows.
Ventilator Settings-2§	Bi-level PEEP-high* Bi-level PEEP-low* TIMEinsp (inspiratory time)* TIMEexp (expiratory time)*	These are either drop-down list selections or numeric entries. Numeric entries can be manually entered or entered using the increment-up/down arrows.
	Apnea V_T*† Apnea RR*† Apnea delay* Apnea mode*†	Apnea delay alarm default is 20 seconds. Adjustment can be manually entered or entered using a drop-down menu.
Measured	P_{AWP} (peak airway pressure)* f_{tot} (respiratory frequency)* I:E (inspiratory/expiratory ratio)* Mean AWP (mean airway pressure)* Minute volume* $V_{T\text{-exhaled}}$* $\dot{V}_{E\text{-spont}}$ (spontaneous minute ventilation)* AWT/HME (airway temperature/heat-and-moisture exchanger)* NO (nitric oxide) (ppm)* NO_2 (nitrogen dioxide) (ppm)*	Same as above
Alarms (see Fig. 3)	Low inspiratory pressure* Low PEEP*	Same as above
	Low exhaled V_T* Low exhaled $\dot{V}_E$* High RR* High peak pressure* Oxygen high* Oxygen low*	The oxygen analyzer high/low alarm defaults are 100% and 21%, respectively. Adjustments can be entered manually or entered using the increment-up/down arrows.
Mechanics	Plateau pressure*†	These are either drop-down list selections or numeric entries.
	NIF (negative inspiratory force)*†	Numeric entries can be manually entered or entered using automatic incremental arrow/stylus interface.
	f/V_T (respiratory frequency divided by tidal volume)†	This is a calculated Field
	Static CL (compliance)†	This is a calculated Field
	S_{pO_2} (oxygen saturation measured via pulse oximetry)* $ETCO_2$ (end-tidal carbon dioxide)*	
	VC (vital capacity)*†	This is a calculated Field
	RES_{aw} (airway resistance)†	

(*Table continues*)

*Choose from a list, a selection of single or multiple phrases, or enter free-text.
†Adult database only
‡Neonatal database only
§Not used in the neonatal database

Table 1. Continued

Tab	Fields	Clinician Interface
Weight & Saturations‡	DOL (day of life)‡	
	Weight (g)‡	Identifies current weight
	Weight change (g)‡	Identifies weight change since previous assessment
	Pre-ductal S_{pO_2}‡	Manual entry
	Post-ductal S_{pO_2}‡	Manual entry
Labs	pH* P_{aCO_2} (arterial partial pressure of carbon dioxide)* P_{aO_2} (arterial partial pressure of oxygen)* HCO_3 (bicarbonate)* P_{AO_2} (alveolar partial pressure of carbon dioxide) (calculated) $P_{(A-a)O_2}$ (alveolar-arterial oxygen difference) (calculated) P_{aO_2}/F_{IO_2} (calculated) MetHgb	In the Labs tab, P_{AO_2}, $P_{(A-a)o_2}$, and P_{aO_2}/F_{IO_2} are automatically calculated when the components of the respective formulas are entered.
Tx (treatments)	Inhaled medication 1* Medication 1 dose* Medication 1 time of treatment* Inhaled medication 2* Medication 2 dose* Medication 2 time of treatment* Inhaled medication 3* Medication 3 dose* Medication 3 time of treatment*	In the Tx tab the clinician selects from lists for up to 3 medications and selects the dose and frequency administered.
S.O.A.P. (subjective, objective, assessment, plan)	Subjective* Objective* Secretions* Breath sounds before treatment* Site-Pre (anatomical location in which the clinician auscultates breath sounds before treatment)* HR (heart rate) before treatment Breath sounds after treatment* Site-post (anatomical location in which the clinician auscultates breath sounds after treatment)* HR (heart rate) after treatment PLAN: Comments*	The clinician selects 1 or more programmed words/phrases for each field to compose the notes. Alternatively, the clinician can type the notes into the personal digital assistant.

*Choose from a list, a selection of single or multiple phrases, or enter free-text.
†Adult database only
‡Neonatal database only
§Not used in the neonatal database

field. Fields can also be programmed to oblige the clinician to enter text or numeric data. Conditional expressions can be programmed to prevent unintended data entry. From numeric data certain calculations can be automatically made and displayed. For instance, the system can automatically calculate the ratio of alveolar partial pressure of oxygen to P_{aO_2}, the ratio of P_{aO_2} to fraction of inspired oxygen (F_{IO_2}), airway resistance, the ratio of respiratory frequency to tidal volume, and static compliance.

We chose to use a variety of field types from those available. Selecting from a list requires a simple tap with the PDA interface stylus on each field. On each field's list, tapping an item a second time selects the desired entry. For numeric fields the clinician can use an increment/decrement feature that allows for easy entry by tapping the PDA stylus on an up or down arrow to obtain the desired value. If the entry requires editing, the clinician can manually over-write the displayed entry. In most fields only one selection is required (eg, tidal volume, respiratory rate, or F_{IO_2}). However, in the diagnosis field the clinician can select as many diagnoses as are appropriate. If the diagnosis is not included in the drop-down list, then manual entry is allowed. After the final entry of each desired field is completed, the record is stored in the PDA.

After the first visit to a patient and the related initial data entry, entering data from follow-up ventilator checks, SOAP (subjective, objective, assessment, plan) note documentation, and treatments is convenient in that information that remained

Fig. 4. Palm M-130 personal digital assistant in its cradle, ready to download data. The cradle also recharges the Palm M-130's batteries.

the same since the last visit (such as patient name, medical record number, diagnosis, date, clinician's name, intensive care unit, room number, ventilator number, and ventilator mode) does not need to be re-entered. A quick duplication of the most recent record (performed with 2 taps with the PDA stylus) automatically enters all of that information for the next series of events requiring documentation. Any of the fields can be edited after duplication, if necessary.

Data Download

We download records from the PDAs to the database at the end of each 12-hour shift. The PDA is placed into the cradle (Fig. 4), and when the HotSync button is pressed, all of the data from the PDA are downloaded to Microsoft Access by the SmartList To Go software.

Data Printing

Once the data are downloaded, Microsoft Access and the database containing the downloaded records are opened. The user selects the report icon (Fig. 5) appropriate for the given intensive care unit and shift, and the printer icon is clicked to print the report. Figure 6 shows a sample end-of-shift report.

Data Analysis

Our system allows the storage and analysis of electronically captured data. Numerous data queries are conveniently accessible for quality assurance activity and clinical practice comparison. Table 2 shows examples of some simple queries that have been constructed. Other multiple-field queries can easily be developed.

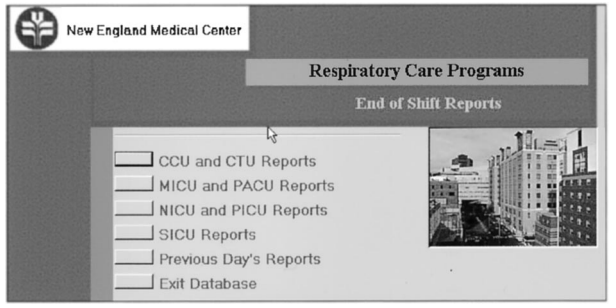


Fig. 5. The reports screen in the Microsoft Access database. After downloading data from the Palm M-130, the clinician clicks on the icon that represents his or her assigned intensive care unit. The end-of-shift report is automatically printed.

Project Cost Analysis

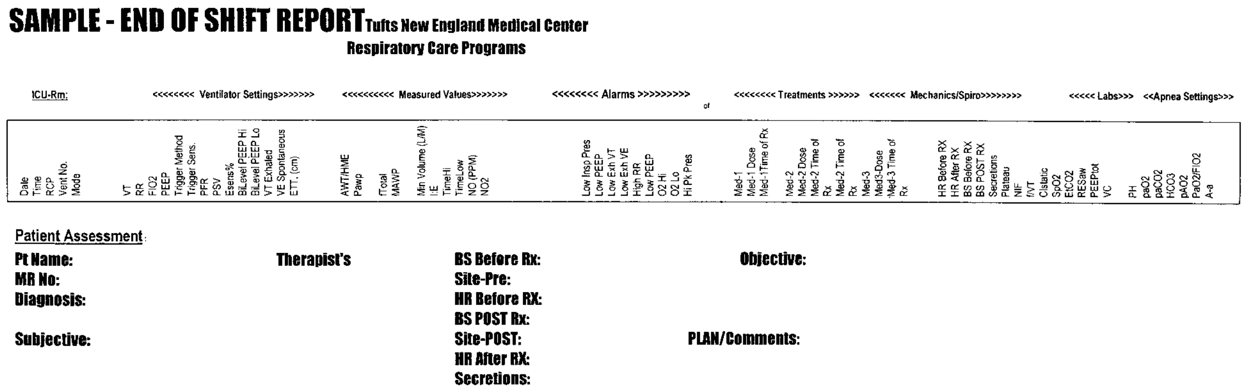
Table 3 shows the primary expenses of our data management project.

Our department assigns clinical work in 6 separate areas for our staff, so 6 PDAs were required. Each PDA requires a separate license. With minor add-on accessories, our existing desktop computers and laser printers accommodated our networking requirements. Separate PDA keyboards were purchased for staff who find them convenient for typing SOAP notes. Hospital-wide expense for the project was $2,309. Anticipated savings will come from (1) the discontinuance of flow-sheet artist design changes (which will instead be performed internally, using Microsoft Access's report function), (2) the discontinuance of purchasing the flow sheets ($0.08 each) that we used before this project began (instead we now use standard, legal-size paper [$0.01 each] to print the reports), and (3) the discontinuance of long-term off-site storage of flow sheet copies (instead, data are digitally backed up on compact discs). Annual savings from those expenses are anticipated to be approximately $5,000 ($3,000 from flow sheets and $2,000 from flow sheet storage).

Discussion

Our system is a cost-attractive way of capturing data electronically. Our system is inexpensive (under $2,400) compared to products professionally designed for similar purposes, such as Clinivision, Tenet, and MediServe, which are in the 6-digit range for entry-level use, plus annual maintenance fees of $15,000–$30,000. That cost is prohibitive for most respiratory care managers.

Not included in our cost analysis was the cost of an independent computer programmer, which we did not use, because all of the software we use is customizable by the user. Programming (or, more accurately, database design) costs were a fixed employee salary cost of the individuals whose interest propelled the project.



SAMPLE - END OF SHIFT REPORT Tufts New England Medical Center
Respiratory Care Programs

ICU-Rm: <<<<<<<< Ventilator Settings>>>>>>> <<<<<<<<<< Measured Values>>>>>>> <<<<<<<< Alarms >>>>>>>>> of <<<<<<<< Treatments >>>>>> <<<<<<< Mechanics/Spiro>>>>>>>> <<<<< Labs>>> <<Apnea Settings>>>

Dale, Time, RCP, Vent No., Mode, VT, RR, FIO2, PEEP, Trigger Method, Trigger Sens., PFR, PSV, Esens%, BiLevel PEEP Hi, BiLevel PEEP Lo, VT Exhaled, VE Spontaneous, ETT. (cm), AWT/HME, Pawp, fTotal, MAWP, Min Volume (L/M), I:E, TimeHi, TimeLow, NO (PPM), NO2, Low Insp Pres, Low PEEP, Low Exh VT, Low Exh VE, High RR, Low PEEP, O2 Hi, O2 Lo, Hi Pk Pres, Med-1, Med-1 Dose, Med-1 Time of Rx, Med-2, Med-2 Dose, Med-2 Time of Rx, Med-2 Time of Rx, Med-3, Med3-Dose, Med-3 Time of Rx, HR Before RX, HR After RX, BS Before RX, BS POST RX, Secretions, Plateau, NIF, f/VT, Cstatic, SpO2, EtCO2, RESaw, PEEPtot, VC, PH, paO2, paCO2, HCO3, pAO2, PaO2/FIO2, A-a

Patient Assessment:

Pt Name:
MR No:
Diagnosis:

Subjective:

Therapist's

BS Before Rx:
Site-Pre:
HR Before RX:
BS POST Rx:
Site-POST:
HR After RX:
Secretions:

Objective:

PLAN/Comments:

Fig. 6. A representative sample of the end-of-shift report filed in the patient's medical record.

Table 2. Examples of Queries for Data Analysis

Field(s)	Criteria	Desired Practice
Minute volume HME (Y/N)	> 10 L/min No	The clinician will not use an HME when the patient's minute volume exceeds 10 L/min
Secretions HME	Thick No	The clinician will not use an HME when the patient's secretions are considered thick.
Total RR Mode	> 35 breaths/min CPAP	One might question the appropriateness of having a tachypneic patient on the CPAP mode rather than a mode that provides supportive assistance.
Inhaled medication administered BS	None Wheezing	This query identifies the occurrences in which there was no bronchodilator administered for a patient who had the potential need for treatment.
BS before treatment BS after treatment	Wheezing Wheezing	With no change between breath sounds before and after treatment, this query suggests the need to change the dose.

HME = heat and moisture exchanger
RR = respiratory rate
CPAP = continuous positive airway pressure
BS = breath sounds

The initial motivation for developing this system was to address a variety of Joint Commission for Accreditation of Healthcare Organizations issues, including transcription illegibility and poor SOAP documentation. The intention was not to introduce a major change to the staff to accomplish this. Rather, the design was focused on configuring the system to mimic a manual pen-and-paper system, so as to create the least amount of anxiety in making a change from the decades-old manual system.

Developing our system was time-consuming until it was implemented. Several hundred hours of programming/design time were required from conception to initial implementation. Since the implementation of our pilot program, changes to such items as lists and report designs are made quickly because the programming/redesign is done on a computer in the department.

Our staff made this project successful by their feedback and frequent suggestions for numerous changes to the database design and content. These changes resulted in a workable replacement for manual entry forms in our department. A department interested in this type of project would require a motivated person who enjoys special projects. That person should be comfortable with computers and have a strong willingness to learn software applications.

This is not a high-maintenance project, once implemented. However, having on-site or on-call people who were part of the pilot project can be very helpful. Our staff who participated in the pilot project have found the system to be accurate, and have been very satisfied in terms of convenience, reduction in data-entry time (compared to the pen-and-paper method), a more professional-looking end-of-shift report, and automatic calculation of several clinical formulas.

Feedback from physicians and nursing administration has been favorable. The only issue that has surfaced is the infrequency of printed report generation. In addition to the 2 end-of-shift reports, we have tested infrared-capable printers located throughout the hospital. They are useful for printing the most recent data from the PDA's patient records.

Security of the data and compliance with federal regulations (in particular, the Health Insurance Portability and

Table 3. Primary Expenses of the Electronic Data Capture Project

Item	Quantity	Cost ($ each)	Totals ($)
Palm M-130 personal digital assistant	6	250.00	1,500.00
License for SmartList To Go software	6	59.95	359.70
Keyboard	4	99.00	396.00
HP IV laser printer legal-size paper tray	1	21.95	21.95
PCI-USB circuit board for Palm M-130 connection to desk-top computer	2	15.50	31.00
Total			$2,308.65

HP = Hewlett-Packard
PCI-USB = peripheral component interconnect/universal serial bus

Table 4. Features of a Typical Professionally Designed Patient Data Management System

Automated point-of-care documentation, including patient/therapist-driven protocol
Outcomes measurement
Automated financial reporting, including charge capture/billing
Workload assignments and scheduling
Order tracking and processing
Quality assurance management
Complete, timely, and customizable managerial reports
Multi-level security
Inventory and capital equipment management and tracking
Caregiver productivity monitoring

Accountability Act of 1996 [HIPAA]) was a concern with this project. HIPAA's privacy provisions apply to health information created or maintained by health care providers who engage in certain electronic transactions, health plans, and health care clearinghouses. Records within the PDAs are not part of transactions covered by HIPAA regulations. Only single flow sheets printed from this system enter the medical record. However, it was still considered reasonable to ensure protection of the data. To that end the database is protected and maintained behind the hospital's computing firewall. The database is purged of all data daily. Archiving of the data, although not a standard obligation for the respiratory care manager, is done with CD-R compact discs. Finally, the PDA database can be programmed with several levels of password protection. If desired, separate passwords can be assigned for opening the PDA database, updating records, beaming data, and copying records, which prevents unauthorized use of the database.

Table 4 lists the features found in typical professionally designed patient data management systems. Our project certainly does not have the breadth of features that the professionally designed applications have. For example, our system does not currently bill patient charges—a function that professionally designed applications are capable of. However, the database does contain the data for a manager interested in designing a variety of reports for tracking numerous related fields. The opportunity to design customized reports based on the collected data is only limited to one's interests and individual needs.

There is currently no available ventilator interface for the PDA we use. However, if preferred to manual verification and manual entry (which I personally do not prefer), technology appears to be rapidly advancing that will be able to do that. There is a strong potential for an RS-232 type interface with the ventilator, but that would require a substantially more expensive PDA that has the appropriate interface from which ventilator settings can be automatically obtained. As with professionally designed systems, the more expensive PDAs are capable of wireless data transfer. The relatively new Bluetooth technology (under development by the Bluetooth Special Interest Group) may allow transferring data from ventilators into PDAs.[8] Bluetooth will connect PDAs to various computing and telecommunications devices, such as laptop computers and network access points.

The current features of our data management system favorably compare to professionally designed data management systems, by providing the ability to conveniently capture clinical data electronically. This will allow the respiratory care manager to save his or her institution money while offering the power to analyze multiple fields of patient data for the purpose of promoting more efficient care.

REFERENCES

1. McCreadie SR, Stevenson JG, Sweet BV, Kramer M. Using personal digital assistants to access drug information. Am J Health Syst Pharm 2002;59(14):1340–1343.
2. Goss L, Carrico R. Get a grip on patient safety: outcomes in the palm of your hand. J Infus Nurs 2002;25(4):274–279.
3. Topps D, Hall D. Electronic procedure logs: taking it further. Acad Med 2002;77(7):756.
4. Jahan A, Gretter B, Smith MP. The anesthesiologist's guide to personal digital assistants. Reg Anesth Pain Med 2002;27(2):193–196.
5. Carroll AE, Saluja S, Tarczy-Hornoch P. Development of a Personal Digital Assistant (PDA) based client/server NICU patient data and charting system. Proc AMIA Symp 2001;100–104.
6. Bird SB, Zarum RS, Renzi FP. Emergency medicine resident patient care documentation using a hand-held computerized device. Acad Emerg Med 2001;8(12):1200–1203.
7. Brody JA, Camamo JM, Maloney ME. Implementing a personal digital assistant to document clinical interventions by pharmacy residents. Am J Health Syst Pharm 2001;58(16):1520–1522.
8. The official Bluetooth info site [Internet]. Overland Park KS: The Bluetooth Special Interest Group; c2003 [cited 2003 Jan 7]. Available from http:www/bluetooth.com/.