

THE EVALUATION OF A PULMONARY GRAPHICAL DISPLAY IN THE MEDICAL INTENSIVE CARE UNIT: A FEASIBILITY STUDY

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Abstract

How a new graphical monitor such as the pulmonary display will be integrated and accepted by the users is an important step when introducing new information and technology in the ICU. We developed a pulmonary display that depicts pulmonary information for an intubated, mechanically ventilated patient. This study observed caregivers attending ICU patients in the presence of the pulmonary display. Attendings observed the pulmonary display an average of 3 times per visit whereas nurses glanced at it at least once per visit. The pulmonary display showed distinct patterns demonstrating the changing underlying pulmonary physiology. Based on analysis of questionnaires, the pulmonary display was perceived as useful information, a desirable addition to the current ICU monitors, and an accurate representation of patient pulmonary information.

Introduction

Monitoring and assessing patients in an intensive care unit (ICU) presents a challenge to caregivers. The Cleveland Clinic Foundation reports that one of every five ICU patients who died was misdiagnosed. Further, in 44.4% of the discordant cases, management would have been modified had the autopsy diagnosis been made pre-mortem. Pulmonary complications that are often misdiagnosed or go unnoticed are bronchospasm, pneumothorax, obstructed endotracheal tube and endobronchial intubation. In one study, 32% of the patients with pneumothoraces were misdiagnosed and spontaneous pneumothorax was missed in 39.4% of the patients.[1]

Nearly all critical events can potentially be identified and corrected early enough to prevent major patient injuries.[2] Monitoring systems that increase situation awareness shorten the time between the occurrence of an unexpected event and the correction of the event.[3, 4] Therefore, a graphical display that integrates and organizes data is needed to help the caregivers assimilate the information and make efficient medical decisions.[5]

However, traditional medical monitoring displays are not designed to help clinicians detect critical events. Most medical monitoring systems use a “single-sensor-single-

indicator” (SSSI) display paradigm.[3] As a result, clinicians must observe and integrate multiple data elements generated by the independent sensors. This process of sequential, piecemeal data gathering may be an impediment to a coherent understanding of the patient’s underlying physiological processes.[6] To add even more complexity, researchers have reported that 67% to 90% of the alarms are false and the clinician must also decide when not to treat.[7, 8]

An integrated graphical displays would be an enhancement to the traditional physiological display monitors and may provide better support for diagnosis and treatment of problems involving alterations of multiple physiological variables. Current research has focused on the development of graphical displays to help clinicians assess the patient status accurately and quickly.[9-16] Weinger developed and evaluated a graphic display where variables are displayed as histograms. When all variables were normal, the display showed a normal “horizon”. Test subjects detected changes in 15% less time with the normal horizon display than with numerical displays.[17] Michels developed the comprehensive graphic anesthesia display that organized 32 variables by organ system and showed that changes were seen an average of three minutes sooner.[18] Blike developed a graphical display that mapped physiologic variables into display objects with meaningful shapes. The objects were designed to aid in the reduction of errors by improving the way data was mapped to the anesthesiologist's mental model of cardiovascular physiology. The analysis showed that the recognition and the diagnosis of the etiology of shock was 27% faster using the object display.[19]

We developed a pulmonary display that displays pulmonary information for an intubated, mechanically ventilated patient. The pulmonary display anatomically represents the bellows, airway, lungs, inspired gas, and expired gas and uses color, shape and emergent features to highlight abnormal pulmonary physiology.

How a new graphical monitor such as the pulmonary display will be integrated and accepted by the users in a patient setting has yet to be determined. This study

assessed the acceptance and utility of the pulmonary display when placed next to a patient's ventilator in an ICU. We hypothesized that the user will rank the pulmonary display favorably on a questionnaire regarding the perceived utility and accuracy of the display. We also hypothesized that the pulmonary display will have unique patterns of emergent features with the changing pulmonary variables. Analysis of the pulmonary display graphic during ventilator alarms was assessed to determine the pulmonary display patterns with changing respiratory measurements. We hypothesized that the participants will notice the pulmonary display during the day as they care for the patient. We calculated the daily average of the participant's glances towards the pulmonary display and stratified by subject type (attending, nurse, resident, respiratory therapists).

Background

The pulmonary display was developed and evaluated by our research and design team at the University of Utah. We used an iterative development cycle to create the pulmonary display that presented critical information about the respiratory system with unique combinations of simple shapes and colors as shown in Figure 1. We tested the display for intuitiveness by requesting clinicians guess the underlying critical event of the pulmonary display pattern without prior training. The clinicians were able to guess the anatomical meaning with 98% accuracy, the pulmonary measurement meaning with 91% accuracy, and the underlying event with 79% accuracy.[20] The pulmonary graphical display was then tested in an anesthesia simulator during which clinicians were challenged to treat simulated patients suffering from critical pulmonary events. The clinicians who used the pulmonary display in addition to the physiological monitors were able to detect and diagnose qn obstructed endotracheal tube and an intrinsic PEEP event significantly faster.(ref paper II)

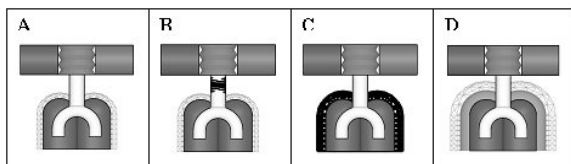


Figure 1: The pulmonary graphical display anatomically represents the bellows, airway, lungs, inspired gas, and expired gas. The green box (upper left) represents inhaled oxygen (FIO₂). The middle grey/blue box is similar to the bellows of the ventilator and moves in the y direction representing tidal volume. The grey box (upper right) represents end tidal carbon dioxide (ETCO₂). The airway is pictured as a simplistic anatomical picture of the trachea and the branched bronchi. (A) The pulmonary display when all measured pulmonary variables are within normal range. (B) The pulmonary display showing airway resistance. (C) The pulmonary display showing decreased lung compliance. (D) The pulmonary display showing an over inflated lung representing intrinsic PEEP.

Methods

The eleven-day evaluation of the pulmonary display took place at the Medical Intensive Care Unit (MICU) at the University of Utah. Investigators observed caregivers

attend eight patients over the course of the study. Thirty-two caregivers (attendings, fellows, residents, nurses, respiratory therapists) were consented and participated in the study. The participants received a 10-dollar gift certificates as compensation. The study protocol was reviewed and approved by the University of Utah Hospital IRB committee. The participating ICU caregivers were trained each morning as needed. Training lasted about 10 minutes and participants were encouraged to ask questions.

At the beginning of each day, two ventilator dependent patients from the MICU were selected by the attending physician to participate in the study. The pulmonary display was shown in one of the patient's room for the first half of the day (8am – 1pm) and then switched to the second patient's room for the second half (1pm – 6pm).

The pulmonary graphical display anatomically represents the bellows, airway, lungs, inspired gas, and expired gas and provided digital and graphical information about the following variables: tidal volume, fraction of inspired oxygen, end-tidal carbon dioxide, airway resistance, and lung compliance. The pulmonary display was shown on a 15' flat screen monitor situated by the patient's bedside next to the ventilator machine. A respiratory monitor, CO₂SMO (NOVAMETRIX, Hartford, CT), that measured the respiratory variables was used to drive the pulmonary display. The pulmonary graphic changed shaped with the underlying pulmonary measurements and displayed the numeric values next to the graphic. The respiratory monitor measured pulmonary parameters such as peak inspiratory pressure (PIP), airway resistance (RAW), total lung compliance (CL), respiratory rate (RR), intrinsic positive end expiratory pressure (iPEEP), and tidal volume (VT) by means of an airflow/pressure/CO₂ sensor device placed in the patient's ventilator tube. The respiratory monitor was located on the floor away from the participant's view.

Two study investigators observed the participants' actions in both of the selected patient rooms during the day (8am – 6pm). The investigators noted how often the participants entered the rooms, the pulmonary actions (such as suctioning) performed, how often a participant looks at the display, and which pulmonary ventilator alarms sounded. The investigators used handheld personal pocket devices (pocket PC PDAs) and clipboards to capture their observations. To facilitate the investigators data capture with the pocket PC, an application was developed using abcDB database 3.0 software. Using the pocket PC application, the investigators were able to quickly capture the room number, the participant entering the room, the ventilator alarm type, and the pulmonary intervention performed. The investigators also noted general comments, caregiver actions, ventilator settings, and ventilator alarm limits on a clipboard with a paper form.

At the conclusion of the day, the health care team members whom cared for the selected patients were given a

questionnaire to determine perceived usefulness and accuracy of the pulmonary display. Participants were encouraged to write general comments regarding the pulmonary display on the questionnaire sheet.

The data was analyzed by reviewing the data captured by the investigators on the pocket PC. We counted how many participants entered the patient’s room based on person type and how often each person looked at the display. For each person type we calculated a daily average and graphed the results.

Next, we matching the pocket PC data with the recorded pulmonary measurement data captured by the respiratory monitor. We compared the pulmonary measurement values from the respiratory monitor data with the pulmonary ventilator alarm types noted in the pocket PC data. For each ventilator alarm noted by the investigators, the recorded pulmonary measurement values were used to recreate the pulmonary display. The pulmonary display pattern generated for each alarm were then grouped and tabulated.

Each of the four questions of the questionnaire was reviewed, analyzed using a student t-test, and tabulated based on person type. General comments on each questionnaire were also reviewed and tabulated.

Results

Caregivers observed the display 878 times during the 545 times they entered the room. Figure 2 shows the distribution by person type of the daily glances at the pulmonary display. Nurses entered the room the most often (336 times, 62% of total number of people entering the room) and comprised the group that looked at the display the most often (411 times, 47% of the total number of observations by all person types). Respiratory therapists entered the room 134 times and comprised 25% of all persons entering the room. Respiratory therapists observed the display 273 times (31%). Attendings comprised the group that entered the patient’s room 61 times (11%). Attendings observed the display 185 times (21%).

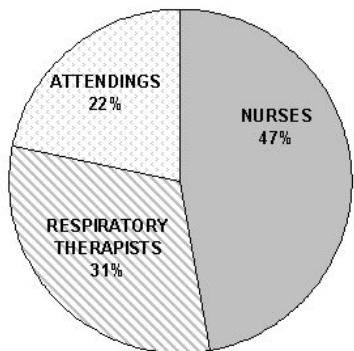


Figure 2 Use of the Pulmonary Display: The graph shows the use of the pulmonary display stratified by person type participating in the study.

The pulmonary display produced eight unique patterns corresponding to the three different emergent features of the display: airway resistance, lung and chest wall compliance, and intrinsic PEEP or breath stacking. Black fingers restricting the anatomical representation of the trachea depicted airway resistance. A decrease in lung compliance was shown by a thick black cage surrounding the lung image (Figure 1C). An image of over inflated lungs appeared when breath stacking (intrinsic PEEP) is detected (Figure 1D).

Pulmonary Display Pattern	Emergent Features	Pressure Alarms	Volume Alarms	Respiratory Rate Alarms
	RAW, CL, PEEP	465 (67%)	425 (53%)	265 (70%)
	RAW, CL	0	2 (0%)	0
	RAW, PEEP	44 (6%)	142 (18%)	8 (2%)
	CL, PEEP	27 (4%)	78 (10%)	48 (13%)
	CL	150 (22%)	17 (2%)	0
	PEEP	9 (1%)	144 (18%)	57 (15%)

Table 1 Pulmonary Display Patterns: The ventilator alarms generated 6 unique patterns. The emergent feature creating each of the patterns is also noted. RAW – airway resistance, CL – total lung compliance, PEEP – intrinsic positive end expiratory pressure

Investigators observed 1910 ventilator alarms during the study (Table 1). The ventilator alarms were noted as volume (808), pressure (695), and respiratory rate (378) alarms types. Of the 808 low minute volume alarms, 53% corresponded to an increase in airway resistance greater than 3 cm H₂O/l/s, a decrease in lung/chest wall compliance less than 70 l/cmH₂O, and an increase in total positive end expiratory pressure (PEEP) greater than 3 cmH₂O. The pulmonary display was distorted similar to the image in Figure 1B to show the corresponding black fingers of the airway resistance element, black cage indicating a decrease in compliance, and an over inflated lung indicating breath stacking. 18% of the volume alarms corresponded to both

an increase in airway resistance and an increase in intrinsic PEEP (similar to Figure 1D). 18% corresponded to only an increase in intrinsic PEEP.

Of the 695 high pressure alarms, 67% corresponded to the pulmonary display presenting all three emergent features. 22% of the pressure alarms corresponded to only a decrease in compliance indicated by a thick black cage surrounding the lung image.

Investigators noted 378 ventilator alarms due to a high respiratory rate. 70% of the respiratory rate alarms showed both an increase airway resistance, a decrease in compliance, and an increase in total PEEP. 15% of the ventilator respiratory rate alarms did not correspond to only an increase in total PEEP. 12% corresponded to a decrease in compliance as indicated by the thick black cage surrounding the lung image and an increase in total PEEP.

A total of fifty-one questionnaires were completed. As shown in Table 3, five questionnaires were filled out by attendings and fellows, twenty-two by nurses, sixteen by respiratory technicians and eight by residents. The subjects were asked to rank how desirable and accurate they perceived the pulmonary display to be. Comparing the ranked scores by person type did not show a significant difference. As seen in Table 2, the average response to usefulness of the pulmonary display was 6.29 +/- 1.91 on a 1-10 scale. The average response to the desirability of adding a pulmonary display to the equipment in the ICU was 6.85 +/- 1.72 and 6.86 +/- 1.59 on a 1-10 scale. Finally, the average response to the accuracy of the information provided by the pulmonary display was ranked 6.76 +/- 1.85 on a 1-10 scale.

Questionnaire Scores by Person Type					
	Nur	RT	ATT/ Fel	Res	Avg
How useful was information provided by the display	6.73	6.06	6.00	6.38	6.29 +/- 1.91
How desirable is the pulmonary display	7.0	6.69	6.60	7.13	6.85 +/- 1.72
Pulmonary display should be added to equipment in ICU	6.86	6.69	6.40	7.50	6.86 +/- 1.59
Pulmonary display showed adequate representation of patient information	6.77	6.94	6.00	7.33	6.76 +/- 1.85

Table 2: The questionnaire was distributed to the ICU caregivers whom cared for the participating patients at the end of the day. Nur-Nurse, RT – Respiratory Therapist, Att/Fel – Attendings and Fellows, Avg- average score with standard deviations.

Discussion

As noted by the frequency they entered the room, nurses are the ones most often by the patient’s bedside. The ICU nurse may often be the caregiver who first detects a medical problem. A graphical display such as the pulmonary display could provide the ICU nurses with the assessment tools necessary to quickly and accurately detect a medical pulmonary event. The nurses glanced at the display every day with an average 1.2 glances per room visit during the study suggesting that the display added some valuable information and was worthwhile for them to observe it during their daily routine. Similarly, respiratory therapists observed the display throughout the study with an average glance rate of 2.0 per visit. An increase in the average glance rate per visit compared to the nurses suggests that the pulmonary display information provided may have been more meaningful and pertinent for their care of the patient. Finally, although attendings entered the room few times, they were observed glancing at the display an average of 3 times per room visit indicating greater interest in the pulmonary information provided by the display.

The pulmonary display presented to the caregiver unique patterns based on the abnormal values of the pulmonary measured values provided by the CO2SMO respiratory monitor. The unique pattern of the pulmonary display depicted the underlying pulmonary physiology of the patient. With such images, caregivers are able to visualize the physiology and make medical decisions based on the underlying physiology causing the problem. For instance, when the respiratory rate alarms sounded, the pulmonary display depicted 4 different patterns. Mostly, the increase in respiratory rate was due to a problem with a combination of airway resistance, a decrease in compliance, and air trapping. This combination could be seen as a result of mucus plugs or lower airway resistance and can be resolved with suctioning or medication. Another pattern showed the increase in respiratory rate due to just air trapping possibly indicating the need for a change in inspiratory:expiratory ratio to allow more time for expiration.

Participants found the pulmonary display to provide useful information, a desirable addition to their ICU monitors, and an adequate representation of the patient’s pulmonary data. Caregiver’s acceptance and positive attitude of the pulmonary display are important to the success of introducing new technology in the medical care setting. Their positive feedback, thoughtful criticism, and interest was encouraging. Based on the subject’s general comments, the investigators learned that the attendings and respiratory therapists mostly valued accurate patient representation when introducing new information and technology in the ICU. The nurses mostly valued their time spent information gathering. The exposure to the pulmonary display was too short for any of the person types to feel comfortable with the information it provided to expect any alterations in current practice. A future study of the pulmonary display will

entail a more in-depth trial and a study designed specifically to assess changes in current practice when administering pulmonary interventions such as suctioning and medicating with bronchodilators.

We recognize the limitations that an observational study presents. Incorporating the use of the PDA data collection application minimized the observed subjectivity of the caregiver's actions. The investigators had a limited number of options to select from when choosing ventilator alarm types, pulmonary interventions performed, and reasons for room entry. The PDA database collection application ensured reliability between observers and between study days. The study was also limited to the day shift hours and we recognize that caregivers working the night shift may observe and rank the pulmonary display differently. The exposure to the pulmonary display was too short for any of the person types to feel comfortable with the information it provided to expect any alterations in current practice and therefore was not examined. A future study of the pulmonary display will entail a more in-depth trial and a study designed specifically to assess changes in current practice when administering pulmonary interventions such as suctioning and medicating with bronchodilators.

Conclusion

The pulmonary display was perceived as useful information, a desirable addition to the current ICU monitors, and an accurate representation of patient pulmonary information. Attendings and respiratory therapists looked at the display more often per visit and were observed utilizing the display when assessing the patient's pulmonary health. Nurses observed the pulmonary display daily when caring for the patients throughout the study. The pulmonary display distorted with abnormal pulmonary measurements creating unique patterns that could be recognized as pulmonary events. Future studies will focus on the pulmonary display's role in the more accurate management of pulmonary interventions.

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