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REVIEW ARTICLE

Developing a Dashboard Software for the ICUs and Studying its Impact on Reducing the Ventilator-Associated Pneumonia

Mohammad Fathi[1], Hamid Moghaddasi[*,2], Azamossadat Hosseini[3] and Monir Ebrahimi Aghdam[4]

[1]*Anesthesiology Department, Faculty of Medicine, Shahid Behashti University of Medical Sciences, Tehran, Iran*
[2]*Associate Professor of Health Information Management & Medical Informatics, Department of Health Information Technology and Management, Faculty of Paramedical Sciences, Shahid Beheshti University of Medical Sciences, Tehran, Iran*
[3] *Department of Health Information Technology and Management, Faculty of Paramedical Sciences, Shahid Beheshti University of Medical Sciences, Tehran, Iran*
[4]*Student of Medical Informatics, Faculty of Paramedical Sciences, Shahid Beheshti University of Medical Sciences Tehran, Iran*

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Abstract:

Objective:

Ventilator-Associated Pneumonia (VAP), a lung infection developing in patients on a ventilator in Intensive Care Units (ICU), is the second most common nosocomial infection and a leading cause of morbidity and mortality in ICUs. To reduce the incidence rate of VAP complication, many healthcare organizations have already developed certain strategies and guidelines. However, there are still high rates of VAP infections mainly due to: conflicting guidelines from different sources, implementing the guidelines at different times and conditions, different ICU caregivers at different shifts, and of course the human mistakes.

Methods:

The present study aimed to develop a dashboard to help reducing VAP incidences in ICUs. To achieve the objective of the research, first, the VAP prevention guidelines were compiled. The object-oriented analysis approach was adopted for designing of the dashboard software. To assess the impact of the developed dashboard on the reduction of VAP events, a pilot hospital was selected and a pilot project was prepared. For the dashboard usability assessment based on user satisfaction, a questionnaire was developed as the survey tool.

Conclusion:

The dashboard was developed and put into operation in a pilot ICU. The results from the t-test (with a probable error of 0.05 percent) indicated a meaningful difference between the number of VAP patients before and after the dashboard implementation with p-value < 0.02. Also, the developed software was evaluated from a usability point of view based on user satisfaction, with health professionals and caregivers of the pilot ICU as the users of the software. The total score was equivalent to 95 percent, falling within the acceptable range of 75-100 percent.

Keywords: Ventilator, Pneumonia, Ventilator-Associated Pneumonia (VAP), Dashboard software, Intensive Care Unit (ICU).

1. INTRODUCTION

As the second most common nosocomial infection, Ventilator-Associated Pneumonia (VAP) accounts for 86% of

* Address correspondence to this author at the Department of Health Information Technology and Management, Faculty of Paramedical Sciences, Shahid Beheshti University of Medical Sciences, Tehran, Iran; Tel: 982122747373, Fax: 982122715150; E-mail: Moghaddasi@sbmu.ac.ir

nosocomial pneumonia [1]. VAP is a lung infection developing in patients on a ventilator in intensive care units. The mortality rate associated with VAP infection ranges from 24 to 76 percent, which drastically exceeds that of patients' primary illness [2, 3]. As reported by the International Consortium Controlling Hospital Infections (INICC) in 2014, the VAP incidence rate stands at 1608 cases per 1000 days of ventilator use [4, 5]. In order to control the VAP infection rate, a number of health institutes have developed VAP-control guidelines, including the *United States Center for Disease Control and Prevention (CDC)* which released the *Hospital-Acquired Pneumonia Guidelines* in 2003.

A noticeable trend which promises a breakthrough is the rapidly increasing use of dashboard software by the healthcare institutions as a tool to regularly measure and improve the healthcare services. The software facilitates access to various information sources in a graphic format [6].

The major differences between a dashboard and other decision support systems in the healthcare section are (a) the preference of graphics display over the numerical presentation of data and (b) the real-time presentation of data. A dashboard typically covers the information on patients, healthcare professionals and the healthcare equipment/machines at use [7].

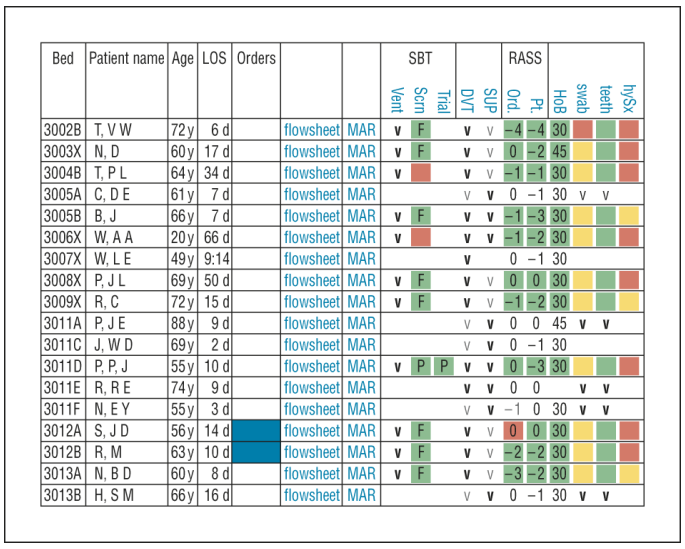
The dashboard packages for the healthcare activities are generally developed in two types: *quality dashboards* and *clinical dashboards*.

Quality dashboards provide graphic information based on quality or performance metrics which helps the managers to recognize the areas in need of improvement [8]. As an example, a quality dashboard is currently being developed in Britain which is intended to act as a measure of staff efficiency. It will feature a range of information on healthcare providers, including nurse-to-bed ratio, doctor-to-bed ratio, the results of the staff and patient surveys, the rates of healthcare-associated infections, and mortality rate [9]. Eventually, the provided data are used by the healthcare high-ranking officials for making appropriate decisions on quality of the services offered by the healthcare providers [10].

Clinical dashboards are designed to provide clinicians with the relevant and timely information they need to inform daily decisions that improve the quality of patient care [11].

By the help of the software, the healthcare providers would be able to observe and carry out the routines and processes recommended in medical guidelines and health protocols in a more accurate manner and at the right time [12].

The Intensive Care Unit (ICU), as a vital section of the healthcare system, is among the dashboard users. The software helps to improve the quality of services and management of resources of the unit. For example, the ICU beds are among the most valuable hospital resources for which demand frequently exceeds supply. A common issue in ICUs is delayed admission or refusal to admit because of bed shortage; as early discharge from the ICU is another challenge for the same reason. Installation of dashboard on the Urban and Provincial hospital network would be very effective in efficient control and management of hospital beds, which would lead to a lower number of such misconducts [13, 14].



Bed	Patient name	Age	LOS	Orders			SBT				DVT	SUP	RASS		HoB	swab	teeth	hySx
							Vent	Scrn	Trial				Ord.	Pt.				
3002B	T, V W	72y	6 d		flowsheet	MAR	v	F			v	v	−4	−4	30			
3003X	N, D	60y	17 d		flowsheet	MAR	v	F			v	v	0	−2	45			
3004B	T, P L	64y	34 d		flowsheet	MAR	v				v	v	−1	−1	30			
3005A	C, D E	61y	7 d		flowsheet	MAR					v	v	0	−1	30	v	v	
3005B	B, J	66y	7 d		flowsheet	MAR	v	F			v	v	−1	−3	30			
3006X	W, A A	20y	66 d		flowsheet	MAR	v				v	v	−1	−2	30			
3007X	W, L E	49y	9:14		flowsheet	MAR					v		0	−1	30			
3008X	P, J L	69y	50 d		flowsheet	MAR	v	F			v	v	0	0	30			
3009X	R, C	72y	15 d		flowsheet	MAR	v	F			v	v	−1	−2	30			
3011A	P, J E	88y	9 d		flowsheet	MAR					v	v	0	0	45	v	v	
3011C	J, W D	69y	2 d		flowsheet	MAR					v	v	0	−1	30			
3011D	P, P, J	55y	10 d		flowsheet	MAR	v	P	P		v	v	0	−3	30			
3011E	R, R E	74y	9 d		flowsheet	MAR					v	v	0	0		v	v	
3011F	N, E Y	55y	3 d		flowsheet	MAR					v	v	−1	0	30	v	v	
3012A	S, J D	56y	14 d		flowsheet	MAR	v	F			v	v	0	0	30			
3012B	R, M	63y	10 d		flowsheet	MAR	v	F			v	v	−2	−2	30			
3013A	N, B D	60y	8 d		flowsheet	MAR	v	F			v	v	−3	−2	30			
3013B	H, S M	66y	16 d		flowsheet	MAR					v	v	0	−1	30	v	v	

Fig. (1). The software provides the ICU staff with immediate and easy-to-grasp information on the unit's situation through presenting real-time graphic (or combination of text and graph) reports.

The intensive care units commonly use the clinical type of dashboard. The software provides the ICU staff with immediate and easy-to-grasp information on the unit's situation through presenting real-time graphic (or combination of text and graph) reports (Fig. **1**). Moreover, making alarms and providing warning messages on due times for medical orders or delays occurred, is among the important features of the software.

2. REVIEW OF LITERATURE

There have been numerous research studies on the effectiveness of dashboard software in prevention and control of the VAP incidences. The following are a selection of such studies.

A Real-time Ventilator Management Dashboard: Toward Hardwiring Compliance with Evidence-based Guidelines was a study by John Starmer *et al*. (2007), the *Vanderbilt University Medical Center (US)*. The study meant to develop a *Ventilator Management Dashboard* capable of reflecting the patient's situation based on the guidelines provided by the *Center for Disease Control and Prevention*. The guidelines covered: DVT prophylaxis prevention, stress ulcer prophylaxis prevention, sedation management and daily assessment of readiness to extubate, 35-45 degree elevation of the head of bed, tooth brushing, and hypopharyngeal suctioning. Each guideline was to be carried out by one or more ICU caregivers, as required, at certain time intervals. While coordinating the ICU personnel, the *Ventilator Management Dashboard* displays various states of compliance with the guidelines in different allocated colors. The major data sources for the software were the clinical documentation system and the Computerized Provider Order Entry (CPOE). An interface engine acted as an interpreter between the data sources and the software. The software system was also capable of producing reports by an individual or by type of practice to help clinicians or managers to find out the hindrances to a successful compliance. In September 2007, the software was installed and made operational in all adult ICUs. It brought about a greater number of care practices over time.

2.1. Implementation of a Real-time Compliance Dashboard to Help Reduce SICU Ventilator-Associated Pneumonia with the Ventilator Bundle

Is the title of another research study by Victor Zaydfudim *et al*. (researchers with the *Vanderbilt University, US*) on the effectiveness of the dashboard developed in the previous study in 2009. The study showed that the average compliance with ventilator grew from 39% in August 2007 to 89% in July 2008, and the average VAP infection rate dropped from 15.2 to 9.3 incidences per 1000 ventilator days in the same period [15].

2.2. Real-Time, Right Care

This is another related research by Debra *et al*. (2013), sponsored by the HealthEast Institution. The outcome was the *VAP Quality Monitor*, a software tool used to monitor clinical transactions. The software gets connected to the electronic medical record system to evaluate the transactions in real time based on the pre-defined care processes in order to prevent VAP incidences. A wall-mounted monitor makes the graphics information available to all people involved in the practice; for example, the unit nurses may have a quick look at the monitor and instantly learn the compliance status for every single patient and go for the appropriate measures.

The study covered the instructions of : elevation of the head of the bed, daily sedation vacations and assessment of patient's readiness to extubate, Peptic Ulcer Disease Prophylaxis - Deep Venous Thrombosis Prophylaxis, Daily Oral Care with Chlorhexidine. By implementation of the project the VAP infection rate fell from 3.07 to zero cases per 1000 days of ventilator use [16].

2.3. Infection Control for Critically Ill Trauma Patients

Is the title of a research study by Heather (2012) on multiple-way infection control in critically ill trauma patients, focusing on ventilator-associated infections. VAP incidence for the trauma surgical population is still a serious Hospital-Acquired Infection (HAI). It is only second to the rate of burn patients in the ICUs; as there are 7.4 cases per 1000 days of ventilator use for burn patients *vs*. 6.5 cases for trauma patients. For a comparison, the stats show the average 3.88 cases for neurosurgical patients.

VAP prevention requires high coordination between the nursing staff, respiratory therapists and other care providers in the ICU, as it requires keeping the elevation of the head of bed at more than 30 degrees, daily sedation management and assessment of readiness for extubation, oral care with chlorhexidine, peptic ulcer disease prophylaxis, and deep vein thrombosis prophylaxis.

Heather's quality dashboard gets connected to the electronic medical record and displays compliance status on monitors in the ICU. Over 4 years of the software use, the researchers observed a 63% reduction in VAP incidences while the treatment period shrank from 12.0 days to 10.7 days [17].

In the following, the Egan's study on the impact of the clinical dashboard on ICU activities is introduced.

2.4. Clinical Dashboards: Impact on Workflow, Care Quality and Patient Safety

is a study by Egan, a researcher with the Massachusetts General Hospital (MGH) in 2006. The MGH had implemented a dashboard system in the same year, January 2006, which displayed the real-time information in the operation room. The software was able to capture, synthesize and display the vital data on a wide-screen monitor installed in the operation room. It was during this study that the idea of dashboard use was extended to the ICUs.

Egan believed that the ICU activities are not only very similar to workflow of the operation room but in many cases are more complicated. So he deemed the dashboard system a sine qua non for the ICUs. Such features as improving coordination between the medical team members, improving management of patient data (patient's allergies, daily status, medical record, medications, injection dose, results of laboratory examinations, and prescribed treatment plan), control of the equipment such as ventilators and displaying the user-tailored data (for physicians, nurses or anesthetists) were considered for an ICU dashboard [12, 18].

Now the present study aims to develop a dashboard software for VAP prevention in the ICUs. Moreover, there will be an assessment of the software based on two criteria: the VAP reduction rate with dashboard in place, and the user satisfaction rate.

The summary of the conducted studies is provided in Table **1**.

3. METHOD

The first step of the study was providing and compiling a VAP prevention guide. As many health institutions had already released their own version of VAP prevention guidelines, the guides published by the CDC, the ICSI and the IHI were selected as the good examples to be carefully reviewed. Following the review, first the items appeared in all the three selected guides were picked up, then the items shared by only two, and eventually the items appeared in only one of them but referred to by various sources. As a result, the items to be included in our guide for VAP prevention were: adjusting the elevation of the head of bed at 30 degree, daily assessment of the patient for readiness to extubate, using ETT holder, setting cuff pressure at 25 cm/Hg, changing the ventilator hose and antibacterial filter in case of contamination or physical damage or as recommended by the manufacturer, using a dedicated suction tube for endotracheal suction of respiratory secretions, using back lumen of endotracheal tubes with dorsal lumen, assessing patient for daily sedation reduction/discontinuation, rotating the oral ETT, regular oral care, using anticoagulation and anti-gastrointestinal bleeding propylaxis medications & antibiotics when ordered by the physician.

Table 1. Summary of the conducted studies.

Study	Design	Sample	Intervention	Control	Results	Distinctive Features
Starmer *et al.* (2008)	Before and after the study	not clear (presumably the nursing staff)	Ventilator management dashboard, presented as a screensaver and accessible from EMR with indicators for each patient for each patient for each element of ventilator management bundle	none	Increasing compliance with bundle elements (RASS score, weaning, Head of Bed adjustment, OB, oral care). Nurse Managers and Charge Nurses note that dashboard allows them to more quickly see when a nurse is overloaded with patient and can divert resources.	Each indicator has traffic light status (green done, yellow imminent, red overdue/not done). Indicators are not always up to date as reliant on timely documentation – problematic if workflow uses 'batch' Documentation

(Table 1) contd.....

Study	Design	Sample	Intervention	Control	Results	Distinctive Features
Zayfudin *et al*. (2009)	Interrupted time series analysis Pre-intervention period January 2005-june 2007 (30 Months), implementation in July 222007, post- intervention period August 2007- July 2008 (12 Months)	Nursing and medical staff	Ventilator management dashboard, presented as a screensaver with indicators for each patient for each element of ventilator management bundle	None	Average compliance with ventilator bundle improved from 39% in August 2007 to 89% in July 2008 (P < .001). Rates of ventilator-associated pneumonia(VAP) decreased from a mean(SD) of 15.2(7.0) to 9.3(4.9) events per 1000 ventilator days after introduction of the dashboard (P = .01). Quarterly VAP rates were significantly reduced in the November 2007 through January 2008 and February through April 2008 periods (P < .05). For the August through October 2007 and May through July 2008 quarters, the observed rate reduction was not statistically significant.	Use of color coding for indicators; green = in compliance, red = out of compliance, yellow = soon due Managers received daily reports on compliance levels
Debra (2013)	Before and after the intervention, the implementation of the project was conducted since October 2009. The time interval of before and after is not clear.	Nursing and medical staff	Ventilator management dashboard, presented as a screen, provided through an electronic health record for each patient as well as the management of pre-defined guidelines relating to the ventilator.	None	In the year prior to the pilot project, the pilot ICU had 3.07 cases of VAP per 1000 ventilator.In the year after the onset of the project, there were 0 cases of VAP	an individual nurse may take a quick glance at the monitor and see that one of his assigned ventilated patients has a “green” status for periodic wean assessment and therefore does not need immediate attention, but another ventilated patient may show a “red” status for daily oral care, meaning the nurse needs to complete that activity..
Heather (2012)	Before and after the intervention. The implementation of the project was conducted since 2007 to 2010.	Nursing and medical staff	The quality dashboard connected to the medical records of a patient displaying the status of doing the guidelines on the monitor in the ICU.	None	This had led to a 63% reduction in the number of VAP cases over the past 4 years although improving our management of those cases that occur through appropriate antimicrobial therapy based on local microbiology.	No cases have been mentioned.

The object-oriented analysis approach was adopted for designing of the dashboard software. The software requirements were recognized by review of the VAP prevention practices of the ICU staff to be integrated into the production plan of the software. Also, Microsoft SQL (Structured Query Language) database management system and the C# language was picked up for developing the software.

To assess the impact of the developed dashboard on reduction of VAP events, a pilot hospital was selected (Modarres Hospital, Tehran) and a pilot project was prepared. Variable of this study was VAP rate which was measured before and after operating the designed dashboard software. The stats on twenty-one ICU's patients affected by VAP were collected based on the Clinical Pulmonary Infection Score (CPIS) for a period of two months prior to dashboard installation. In the second run, a two-month period following the dashboard start-up, the data on twenty-one ventilator-connected patients were being made available to the software and compliance with VAP prevention guidelines was being controlled by the dashboard-provided graphs. In the last stage of the study, the McNemar test, a non-parametric match of the t-test, was run in the SPSS21 environment, with probable error of 0.05%.

For evaluating the user satisfaction based on usability indicator, a questionnaire was used. It included 14 items on the subjects of data entry, compliance of ICU activities with the software's defined guidelines, accessibility and location of tools on the screen, visual features including colors and readability, and the impact of the software on making users practices more qualitative (appendix 1). It was a yes/no questionnaire with the same weight for both choices. The questionnaire was completed by 20 nurses and 3 physicians working with the ICU in the Modarress Hospital.

4. FINDINGS

For preparing the dashboard development design based on object-oriented approach, the data requirements were recognized by a review of ICU staff activities concerning VAP prevention. Some examples of the recognized requirements are: user management including user registration and recognition, patient management, recording medical orders, recording the orders fulfilled by nursing staff, recording the features of the ICU ventilators and the connected equipment, displaying the progress of VAP prevention measures for each patient, and displaying the alarms. Also, the physicians, nursing staff and the software administrators were recognized as the software authorities.

For the purposes of access management and data entry security, multi-level access plan was defined for different groups of users. So each group of users had their own specific panel, tailored to their type of use, and each user could access the system only *via* their specific username and password.

With the software in place, as the ICU patient gets connected to the ventilator, the nurse in charge begins to enter his/her identity data to the system. The patient's physician is responsible to submit the VAP-preventing orders to the system, which is only possible after signing in. After that, anytime the nurse signs in to the software, she/he would be able to see the recorded orders. Also, the nurse is responsible to enter the times of conducting the orders in the software.

A main feature of the dashboard software is being able to capture the patient information at a glance. In our dashboard, for quick transmission of data to the nursing staff, the compliance with the established guidelines are conveyed in certain colors: green for orders already conducted, yellow for orders yet to be conducted (in 30 minutes), and red for delayed practices which should be taken care of immediately. Also physicians may monitor the nurses' activities as the display tells them the compliance status of each patient – *e.g.* how many times an order has been practiced out of the total occurrences required.

In addition to the patient identity data, the developed dashboard is capable of processing the patients' data, recording the time of detaching from ventilator, recording the features of the available ventilator devices in the ICU, running on the defined guidelines, changing the passwords, *etc*.

In order to find the impact of the software on reducing the VAP rate, a before and after study was carried out. In the first phase, a 2-month period prior to dashboard use, 61.9% (13 out of 21) patients on ventilators in the Modarress Hospital's ICU, became infected with pneumonia over the period. In the second phase, following the software installation in the unit, for two months the data for patients on ventilators were recorded in the software and compliance with the pneumonia-prevention guidelines and orders were regularly checked out. The results showed that with dashboard in place, only 24% (5 out of 21) patients under study got infected with VAP.

Eventually, in complementary study of the dashboard impact on VAP reduction, the McNemar test, the non-parametric match of the t-test, was applied to the data collected before and after the software, with probable error of 0.05 percent in the SPSS21 environment. The results showed a meaningful difference between the number of the VAP-infected before and after the dashboard with p-value<0.02. This means the software had a great impact on reducing the number of VAP-infected patients in the pilot ICU.

In evaluation of the dashboard usability based only on user satisfaction, the total score from the completed questionnaires was 19.31 which was equivalent to 95 percent, falling within the acceptable range of 75-100 percent.

Also in evaluation of the nursing staff satisfaction with the dashboard software, the total score was 12.43, equivalent to 88.81 percent, within the acceptable range of 75-100 percent.

5. DISCUSSION AND CONCLUSION

A comparison between the dashboard software introduced in the current study and the dashboards developed in peer studies reveals that: in the Zaydfudim *et al*. (2007) study, there was a 38 percent drop in VAP rate, from 15.2 to 9.3 cases per 1000 days of ventilator use. In the research by Debra *et al*. (2013), a 100 percent cut was claimed - from 3.7 to zero cases of VAP infection. But in the current study, we observed a 61 percent VAP rate drop, from 91 to 35 cases per 1000 days of ventilator use. However, when the factors of environment and working discipline are incorporated into the comparison, the current study actually results in only a 10 percent decrease in the VAP rate.

It seems that the negative factors of, the short period of the study, the low number of nurses contributing to the study, that the software was not connected to medical records, and that the dashboard data could not be displayed on a monitor in the ICU, so that all nurses would be able to capture them at any time, all contributed to the relatively low impact of the software on VAP reduction as compared to similar studies.

The results of the study show that using dashboard software in ICUs could be effective in reducing the VAP rate. Moreover, the VAP prevention dashboard brings about improvement in team working and cooperation between the staff. It provides a systematic solution to get assured that all the patients receive the best possible care services all the time. It proves more important when we consider that in absence of the software many members of the care-providing team may simply ignore their own responsibilities. In addition to giving a considerable cut to the VAP rate, the software causes the ICU workers notice the significance of documentation and the evidence-based approach.

It is noteworthy that the software could be made much more effective by adding such capabilities and innovative features as: developing the mobile phone version of the package for the nurses to fast-code patient data on their cell phones or tablets by the patient bed; making the dashboard connected to the patient medical record for getting the required information from the record and recoding the compliance status in it; providing highly-classified information on the status of VAP infection rate to let the officials know about the effectiveness of the nurses activities and make the appropriate decisions; using of sensors and NFC technology for data entry in a shorter time; making the patients compliance status available to all the ICU nursing staff on monitor(s); and eventually providing the web-based version of the software for easy access and online use.

SUGGESTIONS

At the end, we suggest developing dashboards for prevention and control of other HAIs, including catheter-associated urinary tract infection, blood infection, and surgery infection, as well as developing a dashboard for monitoring the nursing practices in ICUs and CCUs.

LIST OF ABBRIVIATIONS

CDC	=	Centers for Disease Control and Prevention
CPIS	=	Clinical Pulmonary Infection Score
CPOE	=	Computerized Provider Order Entry
EMR	=	Electronic Medical Record
HAIs	=	Hospital-Acquired Infections
ICU	=	Intensive Care Units
INICC	=	International Consortium Controlling Hospital Infections
LOS	=	Lengths of Stays
MDR	=	Multidrug-resistant
VAP	=	Ventilator-Associated Pneumonia

AUTHORS' CONTRIBUTIONS

Mohammad Fathi supervised the project and the clinical applications.

Hamid Moghaddasi proposed the topic; supervised the project and dashboard software design.

Azamossadat Hosseini reviewed the literature.

Monir Ebrahimi Aghadam collected the data and produced the dashboard application.

All authors read and approved the final manuscript.

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AVAILABILITY OF DATA AND MATERIAL

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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Declared none.

APPENDIX 1

QUESTIONNAIRE OF ASSESSING USER SATISFACTION RATE WHILE APPLYING THE VAP CONTROL DASHBOARD SOFTWARE

Please kindly reflect your idea by marking ✓ in the specified box

1. Do you think that the procedures considered in the software match those in ICU ward? **Yes No**
2. Do you think that entering the software information is designed in a way to consume less time? **Yes No**
3. Do you think that the "current status" option in the software well informs you of the instructions' proceeding status? **Yes No**
4. Do you think that the "status summary" option in the software provide enough information about the proceeding status of the instructions? **Yes No**
5. Do you think that he software's menu is easily usable and accessible? **Yes No**
6. Do you think that he terminologies used for the icons correctly inform you about the activity of that icon? **Yes No**
7. Do you think that the time required for showing he pages is at an optimal speed? **Yes No**
8. Do you think that the utilized colors have the proper harmony? **Yes No**
9. Do you think that the writings are clear to read? **Yes No**
10. Is the "exit" option easily accessible? **Yes No**
11. Is the "guide" option easily accessible? **Yes No**
12. Is the "guide file" well instruct you on how to use the software? **Yes No**
13. Is it easy and convenient to work with the software? **Yes No**
14. Does the software affect the quality of your work effectively? **Yes No**

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