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Abstract

Mechanical ventilation is one of the most used medical procedures in intensive care units across the world. In clinical practice, it represents a high level of complexity, especially in both stages, the extubation and weaning protocols. In order to enhance medical and nursing student's training skills regarding those topics, an interactive application was developed to teach basic information for ventilator weaning. The application has two fully graphic modules, which provide theoretical information and a set of clinical cases of patients under spontaneous breathing tests. It also includes information about medical records and interactive panels for weaning criteria and patient clinical condition during the weaning trials. A usability testing was performed with 12 subjects to validate the application usability, where the level of satisfaction with them showed that the app provides a straightforward tool to interact with the critical concepts of ventilator weaning.

Keywords: Ventilator weaning, Mechanical ventilation, Airway extubation, Software tools,

Herramienta médica para el Aprendizaje de Protocolos de Destete Ventilatorio

Resumen

La ventilación mecánica es uno de los procedimientos médicos más usados en las unidades de cuidado intensivo alrededor del mundo. En la práctica clínica, este procedimiento representa un alto nivel de complejidad, especialmente en las fases de extubación y los protocolos de destete. Con el fin de mejorar las destrezas de estudiantes del área de la salud en esta temática, fue desarrollada una aplicación para el entrenamiento y aprendizaje de protocolos de destete ventilatorio. La aplicación cuenta con dos módulos gráficos, los cuales proporcionan el soporte teórico y un conjunto de casos clínicos de diferentes pacientes bajo pruebas de respiración espontanea. Adicionalmente, la aplicación incluye historias clínicas y un panel interactivo con la información de los protocolos de destete y la condición clínica de los pacientes durante estas pruebas. Un test de usabilidad fue realizado a 12 sujetos con el fin de validar la usabilidad y funcionalidad de la aplicación, donde se evidenció un alto nivel de satisfacción de los usuarios con la aplicación, destacando la facilidad de abordar conceptos críticos en ventilación mecánica de forma sencilla.

Palabras claves: Desconexión del ventilador, Ventilación mecánica, Extubación traqueal, Programas informáticos, Registros médicos, Pruebas respiratorias

1. Introduction

Nowadays, mechanical ventilation (MV) is one of the most frequently used medical procedures in intensive care units (ICU) (De-Miguel-Díez et al., 2019)1,031,497 patients received ventilator support in Spain over the study period. NIV use increased from 18.8 patients per 100.000 inhabitants in 2001 to 108.7 in 2015. IMV utilization increased significantly from 2001 to 2003 and then decreased from 2003 until 2015. Patients who required NIV had the highest mean Charlson Comorbidity Index (CCI, where among 30-60% of patients admitted to those centers receive mechanical respiratory support (Nagata et al., 2019). In clinical practice, this procedure represents a difficult high level of complexity (Branson, 2018). Mainly, the extubation phase due to the influence of different criteria and specific patient's conditions (Cohen *et al*., 2009)so varying levels of respiratory support are widely used during the trial. Automatic tube compensation (ATC. The MV can lead to many complications such as airway damage, pneumonia, and lung infections (Stahl, Dahmen, Ziegler and Muhl, 2009; Yousefi, Toghyani, Yazdannik and Fazel, 2015; Zein, Baratloo, Negida and Safari, 2016; Hashemian *et al*., 2018; Medtronic, 2020a). As is mentioned above, the patient extubation represents a big goal and include ventilatory weaning, which is an essential medical procedure that allows the patients to assume spontaneous breathing after a period under mechanical support (Correa-Gutierrez, Castro-Gutierrez and Vera-Rondón, 2008; Kogler, 2009). As an aid to improve those procedures, some techniques have been released to carry out ventilatory weaning in an efficient way, such as protocols to withdraw the mechanical ventilator (MacIntyre, 2001; Stahl, Dahmen, Ziegler and Muhl, 2009; Danckers *et al*., 2013). It is important to note that they involve multiple aspects of decision-making to enhance weaning procedures. As an example, they not only guaranteeing ventilation but also the risk of getting respiratory infections and dependence on a mechanical ventilator. Although, the success of implementing those medical procedures and steps depends on the adequate execution of them by physicians and medical treating staff along with their expertise and skills (Hansen and Severinsson, 2007; Blackwood *et al*., 2011).

Consequently, there is a need to incorporate new interactive breakthrough tools that allow professionals in mechanical ventilation and airway care to get into proper training regarding the implementation of weaning protocols. Currently, there are applications, which provide some techniques and steps related to mechanical ventilation. As an example, The Vital Sync TM is an innovative app, which has several modules that allow tracking the patient's information in the weaning trials and variables involved in that procedure. It also provides information based on several weaning protocols support by medical guidelines (Medtronic, 2020b). However, other apps do not have hefty modules for weaning protocols, such as Basics of Mechanical Ventilation App, Mechanical Ventilation Advanced, and TruVent App (Ibrahim, 2018; DDSurgical, 2020; TruCorp, 2020). Moreover, any of the above tools do not have studies published regarding apps validation throughout usability testing. It means that there is a lack of applications to train medical and nursing staff regarding

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weaning protocols along, not to mention the absence of validation trials to enhance the application modules according to the users' needs.

Therefore, in this work an interactive application with theoretical scientific support and validated by usability testing is developed to teach the most commonly used weaning protocols in clinical practice. This project seeks to improve training medical procedures regarding making decisions in the extubation and weaning processes. Thus, it is a pedagogical aid for specialists in respiratory therapy and rehabilitation to improve their learning and training skills in clinical practice, especially in the management of patients admitted in the ICU.

2. Materials And Methods

The application has two modules based on scientific information and medical guidelines support regarding weaning protocols in mechanical ventilation. Its structure has some features about clinical making-decision and theoretical support. The first mode (*Theoretical foundation)* allows medical students to learn and to train through the theoretical foundation shown interactively. It means that it has an adequate representation throughout flow diagrams, tables, and interactive graphics. Thus, those stages display accurate information regarding weaning protocols, neurological and sedation patient conditions, and weaning criteria.

Meanwhile, the other mode (*Clinical reports)* includes a group of real clinical reports from patients under spontaneous breathing test. It also attaches the steps carried out by physicians into the weaning trials, along with the crucial decisions taken in those tests. In the same manner, that app provides two buttons, which allow users to see the app guide and the explanation of the technical terminology involved in ventilator weaning protocols.

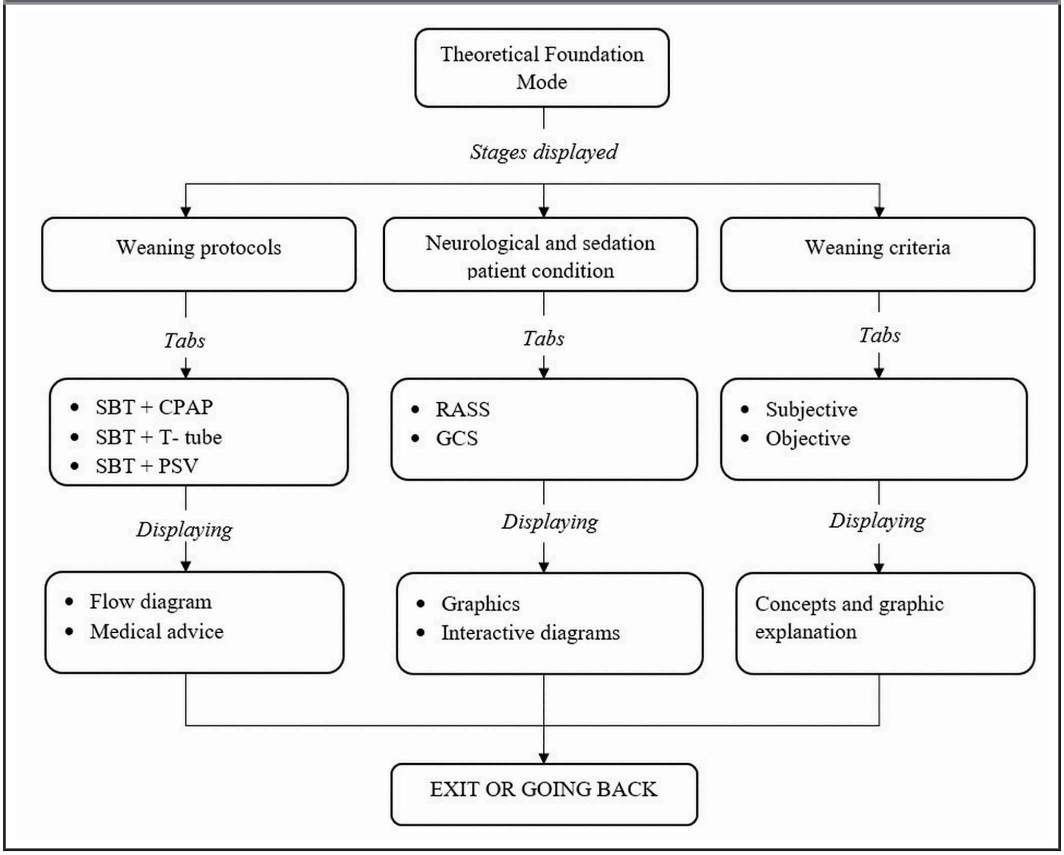
2.1. Clinical Report's Database

The database was recorded from patients under spontaneous breathing test, admitted in the ICU at the Hospital San Vicente foundation (Medellin, Colombia) and treated by their medical and nursing staff. That study was supervised by both the Universidad of Antioquia and the hospital ethical committee under several requirements, according to bioethics technical concerns. The medical parameters and patients' variables included in the app's modules are taken from daily ICU records available in that database. Respiratory parameters, mechanical ventilator configuration, and vital signs are part of the information. The following parameters are taken into account for the modes: Respiratory Rate (RR), pH, body temperature, Inspired Oxygen Fraction (FiO_2), Positive End-Expiratory Pressure (PEEP), Pressure Support Ventilation (PSV), CPAP (Continuous Positive Airway Pressure), Partial Pressure of Oxygen (PaO_2), Partial Pressure of Carbon Dioxide ($PaCO_2$), Oxygen Saturation (SpO2), hemoglobin level, Glasgow Coma Scale (GCS), Richmond Agitation Sedation Scale Index (RASS), Heart Rate (HR), and Systolic and Diastolic pressure (SBP, DBP). Moreover, the teaching tool provides documentation based on plenty of scientific papers and medical guidelines, along with the explanation of technical terms.

2.2. Theoretical Foundation

This mode contains three main stages: weaning protocols, neurological and patient sedation conditions, and weaning criteria, where users could select and interact with their features. The information is represented through several graphics and several interactive diagrams, allowing users to learn about the main concepts regarding ventilator weaning protocols, important clinical tests carried out into either weaning trials, Spontaneous Breathing Trials (SBT), and its criteria. The graphical interface was developed using two open-source programs, such as Python 3.7.3 and QT Designer. It was programmed through the incorporation of Python's library called *PyQt5,* which permits to handle and execute orders into the Graphical User Interface (GUI) from QT designer. The module's structure and the main stages are represented, as is shown in **Figure 1**, where users could select any of them and interact through the tables, graphics, and other representations.

Figure 1. Theoretical Foundation Mode structure flow diagram and its main three stages. Spontaneous Breathing Trial (SBT), Continuous Positive Airway Pressure (CPAP), Pressure Support Ventilation (PSV), Richmond Agitation Sedation Scale Index. (RASS), Glasgow Coma Scale (GCS).



Each stage has its tabs, which allows users to explore the content of them. That information displays several interactive structures such as graphics, diagrams, medical advice, among others. The first stage is represented on the left of the above graphic (see **Figure 1**), where users could choose the desired protocol to interact with their features. They were selected through a detailed review of several scientific papers, medical guidelines, and databases regarding weaning protocols used in the ICU by physicians. Moreover, those diagrams also include the mechanical ventilator settings suggested to withdraw patients treated under a specific protocol.

On the other hand, the second stage presents an interactive content describing the criteria of two crucial tests performed in patients under mechanical support, such as RASS and GCS. Those trials have some steps that doctors ought to follow to get reliable results. However, they do not present the information through interactive resources, and it could not encourage the doctors' attention training with those materials. Therefore, the app's information is fully graphic, along with good representations to enhance medical training in those topics. In the same manner, the third stage presents both subjective and objective criteria used by physicians through graphics and interactive representations. It means that those are supported according to medical recommendations and assessment linked to the patient's vital signs, either mechanical ventilator measurements.

2.3. Clinical reports mode

This mode presents a collection of real clinical reports from patients treated by mechanical ventilation, along with several weaning trials, throughout specifics protocols and procedures based on medical guidelines. Each clinical report has the whole clinical information and treatments carried out into those patients in the weaning trials. Therefore, users could deeply analyze the patient's situation through the steps and medical procedures applied until the end of the weaning test. In the same manner, that module includes the mechanical ventilator settings and parameters applied during the weaning attempts and the doctor's explanations about patients' evolution in those trials.

Users should select a specific clinical report along with the weaning trial in order to see the features and the parameters displayed in that panel. Once users have selected them, they are able to access the panel with the following features: *X-ray images, weaning criteria panel, clinical assessment, Paw-V curve, and weaning protocol carried out.*

The app provides two buttons to support and help users to use the application adequately. Both *Theoretical Foundation* and *Clinical Report* modes include them, and users can access and explore them whenever they want. Those aids are *User guide and Terminology.*

2.4. Usability testing and statistical analysis

A usability testing was performed in order to assess user satisfaction, and for finding usability problems of the application developed. This study does not represent any risk for the participants. However, personal information was requested to fill out the forms of the trials. Thus, informed consent was written with the whole explanations and the details of the activities to carry out into the usability test. That informed was presented and approved by the Bioethical Committee from the Medicine Faculty at the Universidad de Antioquia.

The usability test contains two stages with twenty-four questions, along with the execution of simple tasks linked to a timer. The first phase provides six questions focusing on different tasks and orders that the user should follow. In the same manner, the second stage has a collection of twenty questions divided into four main stages, which seek to provide information regarding users' satisfaction with the app's features and its structure.

According to a statistical study validated through experimental tests, the sample size in usability trials could be enough with 16±4 subjects. That consideration is useful to find several usability problems for apps, such as design, navigation, functions, among others (Alroobaea and Mayhew, 2014)applications and software products that are growing rapidly in use and that have had a great impact on many businesses. These technologies need to be continuously evaluated by usability evaluation methods (UEMs. Therefore, 12 subjects were the sample size used to perform the test, taking into it as appropriate consideration for that study. They were volunteer bioengineering students from the Universidad de Antioquia, who never used, either see the application before. However, that study does not include consideration user's experience handling apps, either background skills in weaning protocols or mechanical ventilation.

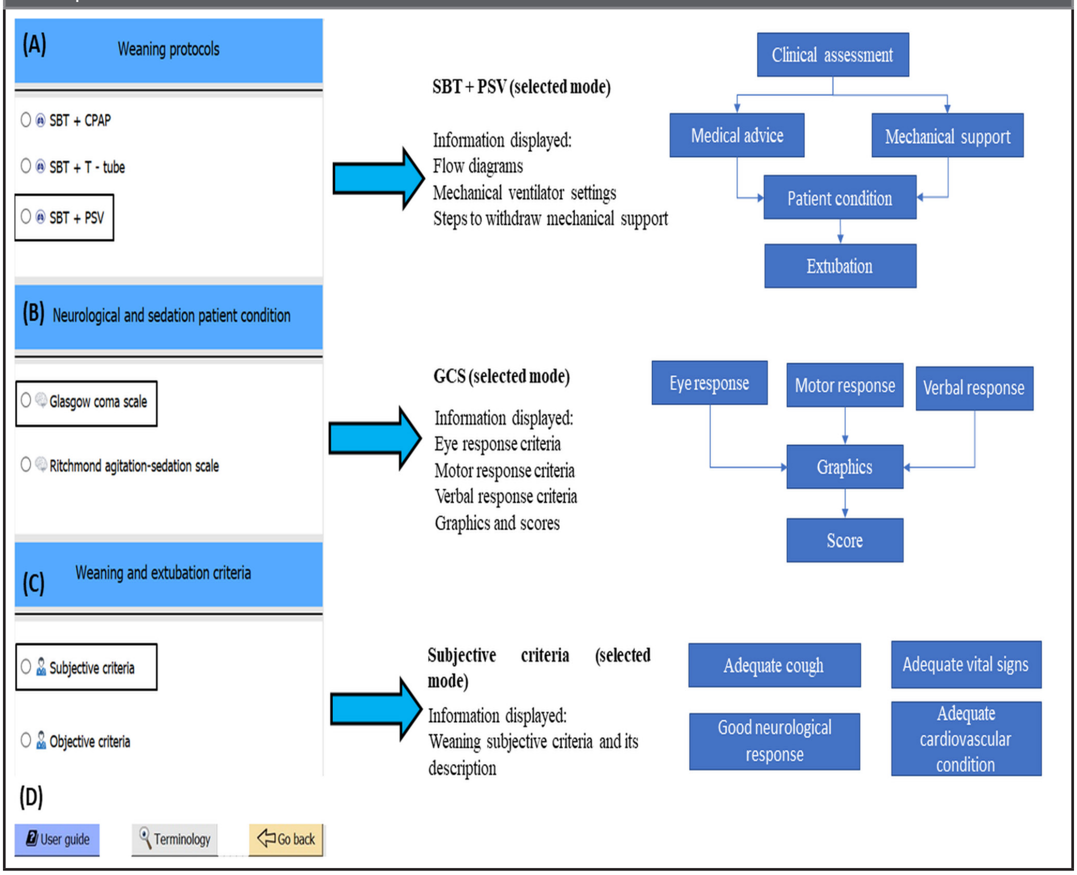
The statistical measures such as mean (μ), standard deviation (σ), and coefficient of variation (CV) were applied to the data in order to see the behavior of the user's time investment into the different app modules and their level of satisfaction using that application.

3. Results

A trial was performed in order to test the application features and its modules. After running the Python console and started it, the main window of the application was displayed. Once it initialized, we obtained the following results.

As is shown in **Figure 2**, the main window of the *Theoretical foundation* displays a panel, which is denoted through the letters A, B, C, and D. The first one (A) displays the weaning protocols available to interact. Those are SBT + CPAP, SBT + T-tube, and SBT + PSV, where users can push the radio button, which represents each protocol. In the same manner, the second one (B) provides two options to choose between two crucial tests carried out by physicians in clinical practice: GCS and RASS. The third one (C) displays two choices regarding both subjective and objective criteria weaning criteria, which doctors should follow in the performing of weaning trials. The last block (D) represents the *help buttons* (user guide, terminology), along with *go back* option. It is important to keep in mind that they appear in the two application modules.

Figure 2. Theoretical foundation mode main window. It that case the SBT+ PSV weaning protocol is represented through a flow diagram at the field graphic. (A) Weaning protocols stage. (B) Neurological and sedation patient condition stage. (C) Weaning and extubation criteria stage. (D) Help app buttons (user guide, terminology) and go back option.



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Neurological and sedation patient condition is shown in **Figure 2.B.** The GCS trials displays three stages, which are fully interactive and represented through images. In that test, doctors provide a score according to three patient's stimuli, such as eye-opening response, verbal response, and motor response. Therefore, with that module, doctors could train and learn through interactive graphics divided into those patient stimuli.

Weaning and extubation criteria is fully graphic and interactive (see **Figure 2.C**.), as the others presented above. It shown the representation of the subjective criteria throughout graphics. It also provides users the option to see the explanation of them through pushing a bottom located below each graphic. Moreover, both pictures and the explanation are referenced.

In **Figure 3**, is presented the interactive module of the first clinical report and the third weaning trial (WT3) registered on the database. It has a set of stages and graphics, which are: (i) *Clinical reports and weaning trials:* It is a block, which presents a set of clinical reports along with the weaning trials. Users can choose and switch to another clinical report or weaning trial whenever they desire to see and explore the weaning protocol carried out, as well; (ii) *Patient information and clinical evaluation:* A graphic stage shows the patient's anthropometric measures and a summary of their clinical background. It also includes the medical reports and notes about the mechanical ventilator treatment, weaning trials, and the statement into the ICU; (iii) *Comments:* Below to the stage mentioned above, a block shows the most relevant information and notes taken by doctors through the weaning trial. It also provides the decisions carried out in that test, and the explanation of the final decision. It means whether the patient overcomes the weaning trial or not. For instance, in that result, the patient did not pass the test due to his level of agitation and diaphoresis; (iv) *Pressure vs Volume Curve:* This graphic is displayed along with both inspiration and explanation curves during the weaning trial. It also provides the mechanical ventilator and settings programmed by physicians. Therefore, users can analyze that graphic and conclude its condition and well technique to perform into a specific weaning trial*; (v) X-ray image:* As part of the graphic filed, an x-ray image is displayed, which provides users information about breast patient anatomy. Each image was taken the same day as the weaning trial. Moreover, it has a panel, which allows zoom, move, and save the image.

Therefore, it is possible to appreciate the desire details of the x-ray image interactively*;* and *(vi) Weaning criteria:* The *clinical reports* provide an interactive panel, which has a set of sliders with information according to weaning criteria. A bunch of colors shown in the right of the panel represents the meaning of the slider's colors. Blue represents the range of typical values according to weaning criteria. Green means that the slider value meets the criteria. Orange is displayed when the value is over the boundary, and red means that the value is out the normal values and represent a risk of extubation failure. It is crucial to keep in mind that users could analyze the fulfillment of those values in comparison with weaning criteria and compare them with their relationship with decisions made by doctors in the specified weaning trial.

On the other hand, in **Table 1**, is presented the results and the statistical measurement of the first phase of the usability testing. It is important to consider that the mean values of the data are shown along with the standard deviation. The first column represents the time invested for each user in the targeted task to finished it; there, it is possible to appreciate that the higher value (188,62 ± 6,67 seconds) is for task 6 and the lower one (20,48 ± 6,31 seconds) is for task 1, respectively. In the same manner, the second column displays the mean of the mistakes made by users for each task, where the highest values match to task 6 (1,83 ± 0,94), and the lowest one corresponds to task 1 (0,00 ± 0.00). Finally, only 10 participants could finish the task 4 without problems; meanwhile, the other tasks did not represent some inconveniences.

Figure 3. Clinical reports module main window. It shows the medical patient information of the first clinical report and the third weaning trial (WT3) performed. The screen shows the medical patient information, such as clinical evaluation, comments during the weaning test, graphics (Pressure vs Volume Curve and X-ray image), and an interactive panel for weaning criteria.

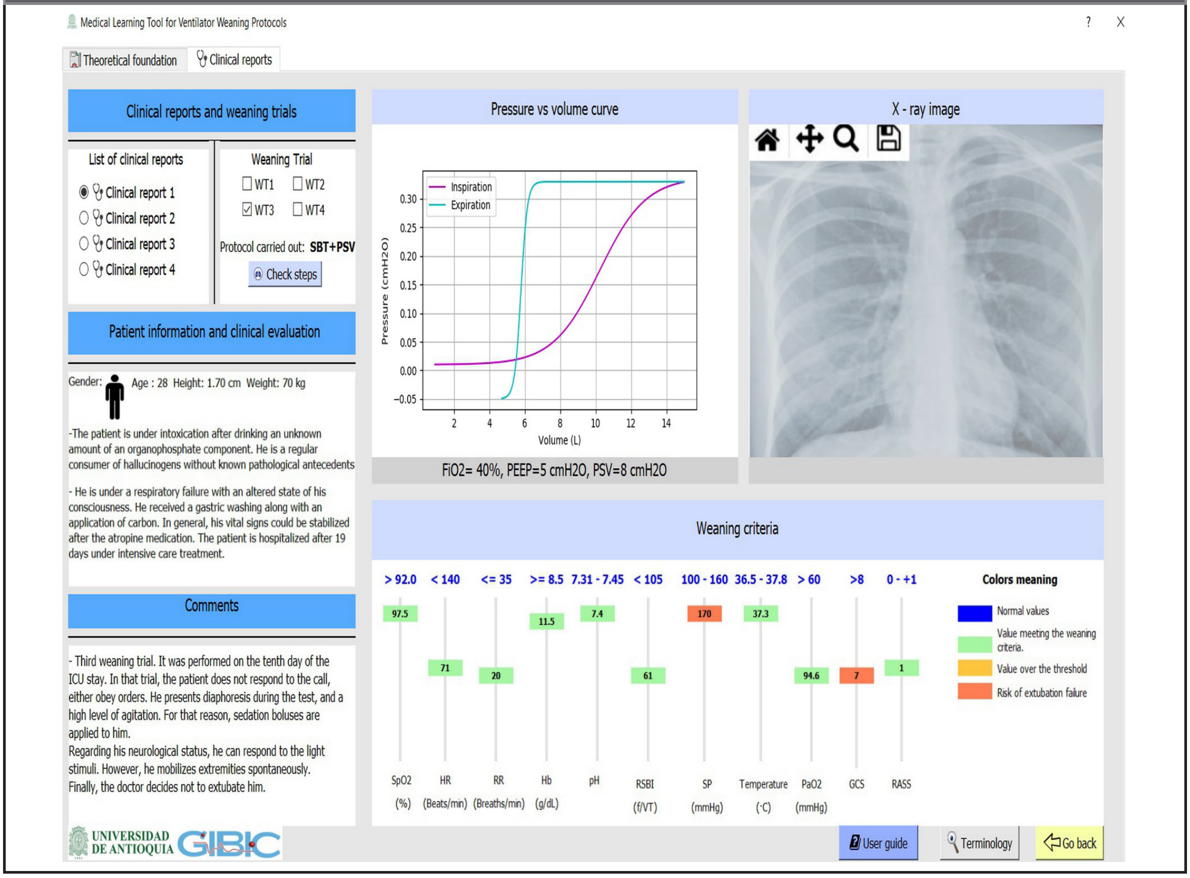

TABLE 1. TASKS AND RESULTS OBTAINED IN THE FIRST TRIAL PHASE. ITEMS DESCRIPTION AND THE STATISTICAL MEASUREMENTS ACCORDING TO THE TIME INVESTED IN EACH TASK, THE MISTAKES MADE BY USERS IN THOSE ACTIVITIES AND THE NUMBERS OF PARTICIPANTS THAT COULD FINISH THOSE ACTIVITIES ACCORDING TO THE TASK DESCRIPTION.

Task description	Mean value and deviation standard of the time invested for each task (seconds)	Mean and deviation standard value of mistakes for each task	Number of participants that finished the task successfully
Task 1: Please, initialize the python a console. Then, push the button (start) and open the Theoretical foundation tab.	20,48 ± 6,31	0,00 ± 0.00	12,00
Task 2: Please, open the Theoretical foundation module. Then, going to weaning protocols and explore it.	68,21 ± 4,59	0,92 ± 0,79	12,00
Task 3: Please, open the Theoretical foundation module. Then, going to neurological and sedation patient condition and explore it.	75,79 ± 3,67	0,50 ± 0,67	11,00
Task 4: Please, open the Theoretical foundation module. Then, going to weaning and extubation criteria and explore it.	48,16 ± 4,45	0,83 ± 0,83	10,00
Task 5: Please, check the functionality of the help buttons (terminology, user guide, and go back) and its features.	93,49 ± 2,22	1,25 ± 1,06	12,00
Task 6: Please, open the Clinical Reports module. Then, check and explore its features and tools.	188,62 ± 6,67	1,83 ± 0,94	12,00

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The results of the second part of the usability testing are shown in **Table 2**. It presents the questions according to the satisfaction level with the application features. It is possible to appreciate that the whole mean values are greater than 92%, and the coefficient of variation values is less than 10%. Thus, those means could be considered as a representative measurement of users' level of agreement for each question presented into the usability testing.

TABLE 2. DEGREE OF AGREEMENT VALUES AND RESULTS OBTAINED IN THE SECOND TRIAL PHASE ACCORDING TO SOME QUESTIONS REGARDING SATISFACTION LEVEL WITH THE APPLICATION FEATURES

Questions regarding level of satisfaction	Mean value and standard deviation	Coefficient of variation of the degree of agreement (%)
Are you satisfied with the different executions and commands through the application tasks?	97,92 ± 3,34	3,41
Do you consider the execution of the different features and commands into the application modules easy?	93,33 ± 5,37	5,75
Are you satisfied with the whole information available in the application's modules?	92,50 ± 4,52	4,89
Are you satisfied with the application features and its graphic interface?	96,25 ± 7,72	8,02
Are you satisfied with the application functions and characteristics?	96,67 ± 6,85	7,09

4. Discussion

This medical tool provides a convenient option to interact and learn the main information regarding weaning protocols in mechanical ventilation in a novel and straightforward way. Users could learn through the theory exposed to the *Theoretical foundation* module and validate this information with real clinical cases of patients intoxicated under organophosphate compounds.

On the other hand, several studies have shown how useful and convenient are learning tools for teaching topics regarding both cardiovascular system and mechanical ventilation through different mathematical models (Serna, Hernandez and Mañanas, 2010). Those applications provide useful tools for both medical and nursing students to get into with quintessential topics for learning and attain some expertise through real case reports (Hernández-Valdivieso *et al.*, 2011). Other studies have demonstrated the impact and usefulness of clinical cases and medical records, which make meaningful encourage training and education for healthcare students (Alhaqwi and Taha, 2015; Florek and Dellavalle, 2016). However, there is an absence of tools for medical education, especially in countries with low-income and the invention of novel technological strategies to enhance medical skills like Colombia (Salazar-Sánchez *et al.*, 2019). Therefore, the interactive tool developed in this project provides users to reach knowledge about weaning protocols, and clinical management based on real clinical reports. Moreover, the application does not represent high costs due to it was developed over open-source platforms (Python and QT designer). Although there are some applications with hefty modules for both respiratory and cardiovascular systems along with simulated responses, they represent a high cost due to their licenses (Salazar-Sánchez, Hernández-Valdivieso, Botero-Ospina and Cortés-Daza, 2017); thus, they could not be accessible for everyone, especially in countries with low economic incomes and resources.

5. Conclusion

This learning tool provides a novel and suitable option for both medicine and nursing students to get into with the essential topics concerning weaning protocols in mechanical ventilation. In the same manner, they will be able to learn and to attain some expertise in those topics without being at the ICU. Therefore, risks and other factors associated with carrying out medical procedures with patients under mechanical ventilation will not appear when users use that application.

Moreover, the present project presented a useful learning tool validated through usability testing, presenting some advantages over others that do not have a report of that validation process. However, medical learning tools should have proof of both theoretical and app content validation throughout the participation of expert personnel in mechanical ventilation and airway extubation.

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