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REVIEW ARTICLE

The Integration of Technology and Innovation in the Development of Patient-Centered Medicine in the Intensive Care Unit: A Literature Review

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ABSTRACT

Since the advent of intensive care units in the twentieth century, several advances have been developed in relation to diagnosis, organ support, and treatment modalities. However, the environment for professionals, patients and their families continues to be stressful and uncomfortable. Optimizing the working conditions and processes of intensive care units is of great significance for improving efficiency and minimizing human errors. Innovations and technological advances can also bring higher quality and safer medicine, as well as greater personalization and a better experience for critically ill patients. This article reviews the progress in the related fields that could be the trend in the coming years for the formation of intelligent intensive care units. It is discussed how thinking about design, structure, equipment, less invasive monitoring, expansion of digital transformation, incorporation of artificial intelligence, in addition to the perspectives of these changes on the multidisciplinary team, can be important in the search for patient-centered care in the future of the intensive care units.

Keywords: Critical care, technology, patient-centered care, artificial intelligence, intensive care units.

1. Introduction

Critically ill patients require continuous monitoring and extreme agility in carrying out interventions aimed at reversing and stabilizing organic dysfunctions. Therefore, the intensive care unit (ICU) environment is characterized by heterogeneity and complexity. Despite much evolution in the core elements comprising the foundation of intensive care systems, there is a large amount of equipment in the ICU that has been in operation for a long time.[1] The past half-century saw dramatic advancements in diagnostic, organ support, and treatment modalities, but further improvements are needed to achieve high-quality personalized care.[1]

Even with advances, the ICU's multidisciplinary team has been working in a high demand stressful environment with pressure for results.[2] In this scenario, it is easy to ignore patient changes and, thus, make mistakes. A well-planned, modern, and intelligent ICU can be associated with greater efficiency with fewer medical service errors caused by human factors.[3] The support of technology can be extremely important for a better allocation of human resources and for the optimization of the use of complex instruments and equipment.[3]

Furthermore, the challenges related to the ICU became more evident after the Coronavirus disease 19 (COVID-19). The need for remarkable adaptability and flexibility, motivated by fluctuations in demand and the need for daily workflow processes and protocols, safer ICU design for the multidisciplinary team, improved communication with families, agile research, expansion of digital transformation and incorporation of artificial intelligence are examples of opportunities for improvement.[4]

Despite the complexity associated with the intensive care environment, it is a very rich field of opportunities for improvement, requiring continuous development to better prepare itself for the new challenges. Patients must be the focal point; therefore, strategies for a more personalized care for the critically ill, supported by the current innovation and technological advancement, must be developed (figure 1). Thus, the objective of this article is to review progress in these related fields and reflect on the critical care response to the challenges in the years to come.

2. Challenges and opportunities in critical care

2.1 Design and structure of the ICU

It has been shown that the physical environment can affect the physiology, psychology, and social behaviors of ICU patients and staff.[5] The process of changing the ICU from a hostile environment to a "home-like" environment through architectural and interior design modifications is important to ultimately provide better care and patient well-being, possibly generating better results.[6,7]

Rethinking the ICU layout and structure, as well as the services for patients and families, is part of this improvement process to minimize environmental stressors.[7,8] The search for a healthy environment involves controlling several factors, such as light, sound, floor planning and room arrangement.[9] The availability of individual rooms allows customization of these factors and makes an ICU bed a more comfortable and quieter environment, thus contributing to maintaining privacy and welcoming communication.[10,11] Single ICU room structures can also facilitate infection control and contribute to patient safety.[10,11]

A second issue concerns the organization of patient equipment. Traditional ICU room design places the equipment around the head of bed. This forces ICU members to enter the room frequently for non-patient contact reasons, such as viewing waveforms, responding to alarms, or adjusting device settings. This workflow may increase the consumption of personal protective equipment (PPE) as well as the number of unnecessary clinical interventions.[12] Remote control of devices using Wi-Fi or Bluetooth systems and the advent of artificial intelligence (AI) algorithms to manage vasopressors and mechanical ventilation parameters can be used to reduce interruptions on patients' privacy as well as exposure of the multidisciplinary team to pathogens.[3,12]

Looking to the future, the ideal ICU patient room should also facilitate the provision of patient-centered care, with visibility of patient from outside through smart glass transparent walls, which can be opacified when needed.[2] The nursing station must be near the bedside, so the ICU staff can stay close to patient.[2] To prevent delirium, the ICU room should try to replicate the benefits of the home environment, with furniture, colors, decoration, and natural light windows to simulate a healing natural scene.[13]

Alarms must have their limit settings individualized according to the specific goals and vital signs of patients, so as to minimize unnecessary noise.[9] Another opportunity for improvement is the development of alarms that can be seen or heard exclusively at central monitoring stations or on nurses' mobile tools. The future smart ICU will need different technologies able to monitor and analyze the vital signs and physiological parameters of patients, in real-time, choosing whether to trigger the alarm and send a signal to nurses or doctors.[14]

The structure and access to the ICU may also facilitate the presence of family members, who will no longer be considered visitors, but rather an integral part of the healing process, playing a role in taking care of the patient. In the smart ICU, the patient and caregivers should have control over their environment, including steering the bed to face the window to the outside and managing temperature levels. Apps with artificial intelligence can be used to select a specific menu and entertainment according to the patient's wishes and provide greater connectivity with family members from distant locations. Furthermore, the presence of family at the patient's bedside is crucial for healing, thus allowing extension of visiting times to 24 hours per day, 7 days a week can be an important measurement for better outcomes.[15,16]

However, patient safety cannot be placed in the background. Safe ICU design could ideally feature camera monitoring systems with technology capable of detecting movements to quantify workload, evaluate procedures at bedside and minimize the risk of accidents, such as night falls, for example.[17] Ceiling or wall-mounted monitoring systems allow quick access to the patient in case of emergencies and can also monitor the activity of family members and caregivers.[18] Family members should be guided by the ICU multidisciplinary team regarding rules, behaviors, and the best way to contribute to patient care. Moreover, each ICU must have a dedicated family area with comfortable armchairs and beds for rest, a table, access to food and bathrooms, a storage cabinet and social assistance to help meet the necessities of families under stress.[2]

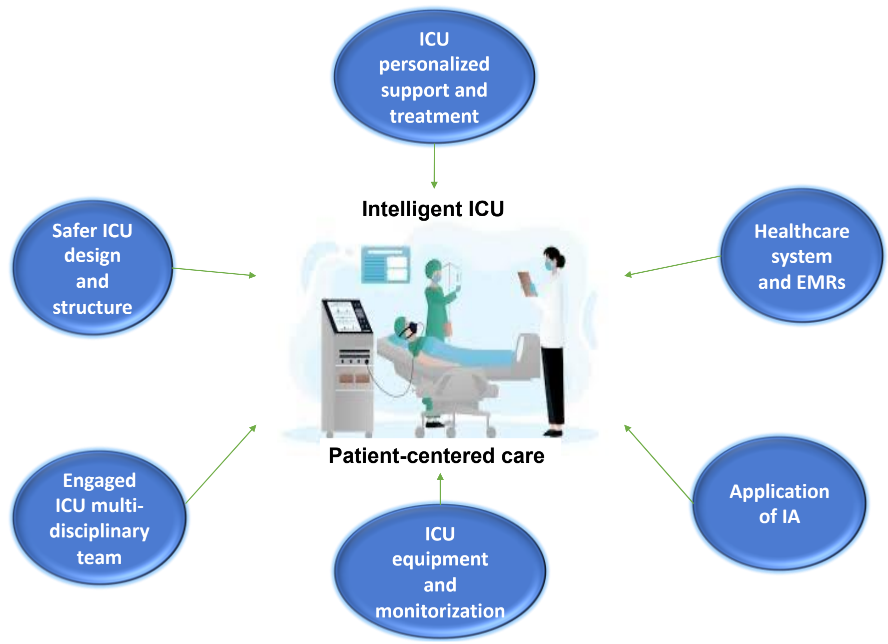

Figure 1. Developing factors associated with the implementation of patient-centered care and intelligent ICUs in the future.

2.2 ICU multidisciplinary team

More than technology and equipment, current and future best practices for critically ill patients require a balanced cooperation of a coordinated multidisciplinary team, including physicians, nurses, physiotherapists, psychologists, clinical pharmacists, speech therapists, nutritionists, occupational therapy specialists, religious support specialists and social workers to accommodate the specific needs of critically ill patients. Members of the multidisciplinary team who are engaged and aware of their patient-centered purpose can contribute to better patient satisfaction and guarantee an integrated plan for treatment.[19] Early mobilizations or active exercises are important interventions that fundamentally depend on well-established processes and highly engaged teams that can reduce the impact of the sequelae of critical illness.[20]

The ICU staff will need to be adept in embracing digital and technological advances, data science and artificial intelligence. In addition to that, upon recognizing that family members will play an integral role in the ICU care, the team must be concerned not only about communicating with their colleagues, but also with patients and families. Poor communication in critical care has been frequently shown as a contributing factor to adverse events.[21] Therefore, ICU workers will require training programs that go beyond teaching basic ICU management skills to ensure practice in non-technical skills, with a holistic, patient-centered, and personalized care view.

2.3 ICU monitoring

Historically, the professional aspects of ICUs have been influenced by the equipment used to support patients and their failing organs. Technical innovations have brought remarkable changes in the equipment for critical care patients.[2] New bedside monitors will allow direct wireless-based information and visualization of patient status (such as vital signs, electrolytes, gas exchange and hemodynamics).[22] Wearable devices with refined and reliable design bring simplicity to monitorization, providing safety and greater comfort to patients, and the measurement of physiological parameters in a non-invasive way can also reduce the need for uncomfortable phlebotomies.[2]

In this way, there has been a rapid development in non-invasive technologies for hemodynamic monitoring. Continuous, non-invasive blood pressure measurement and the monitoring of hemodynamic parameters, especially cardiac output (CO), can be assessed without disrupting the skin or tissues, reducing thrombotic, hemorrhagic, and infectious complications associated with invasive techniques.[22] Newly developed technologies, based on thoracic electrical bioimpedance (TEB) or based on plethysmograph visual signal can be used before cardiac procedures, as well as for intraoperative and critical care monitoring.[23] These methods have demonstrated good correlation between blood pressure and CO values compared with the 'gold standard' invasive methods and their numerous advantages, including the simplicity of application, time- and cost-effectiveness can enforce their further utility.[24,25]

However, in the future, hemodynamic monitoring can go beyond macrohemodynamic parameters such as CO measures. The goal of hemodynamic resuscitation is to optimize the perfusion to meet the organs' oxygen and metabolic needs.[26] Currently, we can say that intensivists are blind to what happens in the microcirculation, which limits the hemodynamic resuscitation at the tissue level. Regional tissue perfusion monitoring, through oxygenation variables using Near-infrared spectroscopy (NIRS)-technology or using direct visualization of microcirculation through video-microscopy can provide specific parameters capable of setting individualized therapeutic goals at the bedside.[26,27] Moreover, the introduction of automated analysis and artificial intelligence into analysis software could eliminate observer bias and provide more specific microcirculatory-targeted treatment options, in real-time.[26]

Together with the exciting development of technical and digital innovations, the healthcare world presents an increase in economic constraints. It is necessary to find ways to improve monitoring solutions access to more patients even in developing countries. Echocardiography is a good example of how the simplification of medical devices can increase their clinical adoption. Wireless and hand-held echo devices are now available, and every doctor can have an echo probe in their pocket to augment clinical examination.[28] In the next years, these measurements would be greatly facilitated by smart systems recognizing heart structures and movements and helping clinicians to properly position the probe.[29]

In parallel with the advancement of monitoring physiological variables, traditional biochemical tests requested daily in the ICU could be replaced by more specific molecules that integrate gene expression protein biomarkers and metabolites, allowing the description of phenotypes directly associated not only with prognosis but also with the usefulness of certain therapies.[30] The development of critical care point-of-care tests that monitor inflammatory and nutritional status, coagulation pathways, and renal function can bring agility to treatments optimization such as antibiotics, individualized diets, and immunotherapies, bringing more personalized critical care treatments in the future. Furthermore, the development of new methodologies capable of accurately monitoring serum drug concentrations may allow for a lower risk of kidney and liver damage in addition to ensuring therapeutic doses of medications.[2] Novel microfluidic devices will be developed for continuous monitoring of drug concentrations and can be integrated into infusion pumps for rapid and automatic medication infusion rate adjustments.[2]

2.4 ICU support and personalized treatments

A challenge in personalizing therapy in critically ill patients is their inherent heterogeneity; however, with the advance of technologies, new devices for organ support will emerge in the next years. Regarding respiratory support, 2 subtypes of acute respiratory distress syndrome (ARDS) have been identified in large observational cohorts.[31] These biologic phenotypes appear to respond differently to standard supportive therapies, and the mechanical ventilation strategy may be personalized for improved outcomes.[32,33] Given this scenario, mechanical ventilators will evolve technologically and will monitor important physiological parameters for the development of ventilator-caused lung injury (VILI) such as asynchrony index, mechanical power, transpulmonary pressure and lung heterogeneity.[34]

Personalization of ICU nutrition is also essential in the future smart ICUs. Ideally, nutrition should be individualized, with accurate markers indicating when energy intake is adequate, minimizing over-and underfeeding.[35] Thus, it is necessary to develop future devices for measurement of energy and protein needs to meet specific targets. Currently, indirect calorimetry (IC) measurement of energy expenditure (EE) is recommended after stabilization in the ICU admission.[35] In the future, we expect to see different techniques for monitoring muscle, such as ultrasound, to assess nutrition risk and monitor response to nutrition.[35] The use of specialized anabolic nutrients such as hydroxymethylbutyrate (HMB), leucine and creatine to improve strength muscle mass is promising in specific populations and deserves future studies.[35]

Another major future challenge is the emergence of antimicrobial resistance (AMR) to most available antibiotics, especially the emergence of multidrug-resistant (MDR) bacteria. For successful treatment of infectious diseases, a prior knowledge of the in-vitro bacteria susceptibility to antimicrobial agents is crucial.[36] Scientists are working on the development of novel and faster methods of antimicrobial susceptibility testing to be applicable in the microbiological laboratory practice.[36] To meet these requirements, there is a current trend in research to explore automation, genotypic and micro/nano technology-based innovations.[36] Automation in detection systems and computer technology for online data analysis and sharing are giant advances toward automated methods.[37] With the evolution of methods in antimicrobial susceptibility testing, we will have faster results and the implementation of more specific treatments in a more agile way.[37]

2.5 Systems that underlie ICU care and applications of artificial intelligence (AI)

Currently, health information technology is widely available even in developing countries. Electronic medical record (EMR) systems can minimize costs and time spent by ICU staff on documentation by focusing on essential data fields and enabling automatic data capture.[38] Furthermore, medical device integration can synchronize data from medical equipment and monitors to the EMRs, generating an efficient and accurate data transfer.[38] Integration of data enables the conversion of the traditional ICU into a learning healthcare system that analyzes and interprets data from various sources to favorably change clinical practice.

Moreover, quick data analysis from EMRs for research, benchmarking, and safe and quality institutional improvement programs can contribute to the education of ICU workers and the implementation of processes and protocols capable of improving cost-effectiveness.[39] The creation of learning healthcare systems sets the foundation for personalized medicine as a medical model that individualizes the care of patients according to risk of disease or the predicted response to an intervention.[40] This feature is especially important in ICUs, where patients present complex unpredictable ways and a timely intervention is important to improve outcomes.

Thus, predicting disease progression can be crucial for critical patients. For clinicians manage this complexity, a careful consideration of underlying etiologies and clinical conditions is necessary. In the past, prognostic models focused on mortality using simple ordinal disease severity rating scores, which had to be tabulated manually by a human. Nowadays, AI can recognize patterns leading to more personalized treatment plans.[41]

Dynamic random forest model (RF) is a type of a computer-driven machine learning technique that can predict outcomes in the ICU.[41] A study by Yoon et al. showed that a dynamic model using random forest classification could predict cardiorespiratory instability hours before these events occurred.[42] In other words, the use of a variety of machine learning tools can lead to the identification of alert artifacts and filtering of bedside alarms, displaying real-time stratification to assist clinical decision-making at the bedside.

Another area in which machine learning can be important is to predict symptoms. A recent study, focused on pain experienced by critically ill patients, demonstrated that vital signs, continuously measured in the ICU, can be used to predict pain with high accuracy using a RF model as well.[43] These results show that machine learning can be used to continuously evaluate pain and recommend starting analgesic medications earlier.[43] This algorithm may be even more relevant in patients who cannot communicate, which could improve their ICU experience.[43] All these examples show how AI can serve as an aid to more personalized medicine in the coming decades.

3. Conclusion

Despite recent advances in intensive care over the years, the substantial heterogeneity of illnesses in critically ill patients and the psychological stress that involves ICU workers make this an extremely challenging environment for sufficient progress regarding therapies and outcomes. To continue progressing, critical care infrastructure needs to be transformed and the focus must be on personalized and patient-centered medicine. Technology will continue to provide tools to redesign processes, improve efficiency and minimize human errors in intensive care. However, it is imperative that the focus on developing non-technical skills must be prioritized, with an emphasis on communication, empathy, and engagement of the ICU staff.

Innovation and technology are allies. In the future, we believe that critically ill patients will increasingly use non-invasive, wireless, and wearable sensors, bringing them greater comfort. The signals and data will be filtered, analyzed, and integrated by intelligent software and algorithms, predicting, and preventing clinical deterioration and adverse events, as well as improving symptoms management. Global variability of critical care will remain forever, but continuously working on improving quality and safety processes to achieve this future vision of smart ICU, including a more humanistic and personalized care, with fewer errors and a better experience, must be the ultimate goal.

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