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Data Science in the Intensive Care Unit

Data Science in the ICU

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Abstract

In this editorial, we comment on the current development and deployment of data science in intensive care units (ICUs). Data in ICUs can be classified into qualitative and quantitative data, with different technologies needed to translate and interpret them. Data science, in the form of artificial intelligence (AI), should find the right interaction between physicians, data, and algorithm. For individual patients and physicians, sepsis and mechanical ventilation have been two important aspects where AI has been extensively studied. However, major risks of bias, lack of generalizability, and poor clinical values remain. AI deployment in the ICUs should be emphasized more to facilitate AI development. For ICU management, AI has huge potential in transforming resource allocation. The Coronavirus Disease 2019(COVID-19) pandemic has given opportunities to establish such systems, which should be investigated further. Ethical concerns must be addressed when designing such AI.

Core Tip: Data in intensive care units(ICUs) can be classified into qualitative and quantitative data, with different technologies needed to translate and interpret them. Data science, in the form of artificial intelligence (AI), should find the right interaction between physicians, data, and algorithm to maximize the utility and AI deployment in the ICUs should be emphasized more to facilitate AI development. Individual-level applications, such as disease prediction, and ICU-level potentials, such as resource allocation are both of paramount importance.

INTRODUCTION

The intensive care unit (ICU) is a data-rich setting where the right decision can mean the difference between life and death. This gives the ICU the perfect opportunity to explore the impact of data science, combined with artificial intelligence (AI), to maximize the utility and benefits. However, challenges remain because the interpretation of an incredibly huge amount of data is still a black hole, with many questions unanswered. Although many models have been created, their clinical applications are limited. Attention is mostly paid to individual-level decision making, such as diagnosing and predicting the prognosis of a specific disease, while potentials at a more macroscopic level, such as ICU resource allocation, are largely omitted.

Generally speaking, data in the ICU can be classified into qualitative and quantitative data. Qualitative data include graphical data, such as waves on the ventilation machine, and radiological data, such as x-rays or computed tomography (CT) scans. Such data need to be translated first before being further calculated. Recently, we have seen a substantial number of researches focusing on such a translation process [1-4]. Quantitative data in the form of numbers, such as physiological parameters, laboratory results, dosage of medication, and ICU bed capacity, are common to intensivists. This kind of data has the advantage of being readily available for statistical analyses without the necessity for further processing into means that are more accessible.

The key to making full use of data in ICUs is to find the right interaction between three roles: physicians, data, and algorithm.**(Figure 1)** Physicians need to ask the right clinical question, which points out the direction of the research and the data we should pay attention to. The data should be collected and interpreted in a way that can be processed by current software. The collection of data should follow certain statistical rules and avoid bias as much as possible. The algorithm can be built to find patterns based on a large quantity of data, and these patterns should target clinical questions raised by physicians.

DECISIONS MAKING AND PREDICTIVE MODELS

Two examples where predictive models are supported by AI in decision making in ICUs are sepsis and mechanical ventilation. Sepsis is a leading cause of morbidity and mortality in critically ill patients. AI models have been studied in different stages, such as the detection, prediction, risk stratification, and management of sepsis. Goh *et al* developed an algorithm with independent, clinical notes and achieved high predictive accuracy 12 hours before the onset of sepsis (AUC 0.94).[5] It also has great potential for improving the early identification of patients who may benefit from the administration of antibiotics. Moreover, it can discover new phenotypes for sepsis, potentially transforming sepsis treatment and offering a more tailored strategy for patients with sepsis,[6] such as the use of glucocorticoids.[7] Clinicians hold a positive view in letting AI take a more active role when managing patients with sepsis.[8]

Mechanical ventilation is another common situation in ICUs. Machine learning can predict the need for intubation in critically ill patients using commonly collected bedside clinical parameters and laboratory results.[9] AI has the potential to identify treatable phenotypes, optimize ventilation strategies, and provide clinical decision support for patients who require mechanical ventilation.[10] Zhao *et al* also created a model for predicting extubation failure in ICUs, with an AUROC of 0.835 and 0.803, respectively, for internal and external validation.[11]

Such an exciting trend should be viewed with caution. Current AI prediction models to diagnose sepsis are at a major risk of bias when the diagnostic criteria vary. The generalizability of these models is poor due to overfitting and the lack of standardized protocols. Similar conditions occur for mechanical ventilation. AI applied to mechanical ventilation has limited external validation and model calibration, with a substantial risk of bias, significant gaps in reporting, and poor code and data availability.[10]

Mamdani and Slutsky summarized three themes in applied AI in medicine, enabling data, AI development, and AI deployment. We believe that AI development and AI deployment should be combined to revise current models and offer tangible benefits derived from current researches. A vast majority of developed ICU-AI models remain within the testing and prototyping environment, and only a handful have been actually

evaluated in clinical practice.[12], which implies the lack of enough evidence to support the clinical values of published models. Focusing more on AI deployment in the form of prospective randomized controlled trials would not only facilitate published models to generate bedside merits but also test and evaluate whether major biases exist and clinical needs can be met in a satisfactory way. The results from deployment testing can, in turn, offer insights into the development and modify the substandard algorithm. **(Figure 1)**

RESOURCE ALLOCATION

Machine learning and algorithm have been widely used to manage resource allocation. Machine learning has been studied for predictive scheduling and resource allocation in large-scale manufacturing systems,[13] and resource allocation strategies in vehicular networks using machine learning have been extensively explored.[14] These settings are similar to ICUs in that both need to capture the value from big data processing and extract useful insights to optimize production and protect resources.

However, in the realm of critical care, where resource can be scarce due to factors such as bed capacity, the applications of machine learning have just shown a glimpse of light. **(Figure 2)** Over the past 2 years, these applications in the context of COVID-19 ICUs offered more chances to lay emphasis on resource allocation. Cheng *et al* used machine learning to predict ICU transfer in hospitalized patients with COVID-19 and concluded that it could improve the management of hospital resources and patient-throughput planning.[15] Similar principles were used to predict the use of ICU resources, such as mechanical ventilation, during the COVID-19 pandemic in Denmark.[15] At a healthcare system level, the National Health Service (NHS) in the United Kingdom (UK) started trials of a machine-learning system designed to help hospitals in England anticipate the demand on resources caused by COVID-19. COVID-19 Capacity Planning and Analysis System (CPAS), a machine learning-based system for hospital resource planning, was subsequently developed that could be deployed at individual hospitals and across regions in the UK in coordination with NHS Digital.[16]

Such models can take the application of AI in ICUs to another level. Although its insight into disease prediction, diagnosis, and management is extremely important, it gives the chance to make the most use of resources, especially in ICUs where demand and supply frequently mismatch. Prediction in interventions, such as mechanical ventilation, would mean that the management groups can foresee changes and mobilize resource, such as equipment and staff, to cope with such demands in advance, which is a positive factor for patient outcomes.

Besides efficiency, another aspect that we must pay attention to is how to answer the ethical questions embodied in resource allocation, to achieve a healthcare system that values equity and sustainability. This implies that ethical considerations must be included and certain ethical principles must be followed when designing the algorithm. Recently, a set of new studies focused on the ethics of healthcare resource allocation, drawing attentions to patient need, prognosis, equal treatment, and cost-effectiveness.[17] Also, numerous comments were made during the COVID-19 pandemic that AI should stick to the ethical standards.[18-20] In a broader setting, the so-called algorithmic fairness highlights specific opportunities where machine learning and, public and population health may synergize to achieve health equity.[21] Challenges remain as what ethical principles matter and what priority should be given to each ethical principle, and coding them into an algorithm has not been intensively experimented.

CONCLUSION

AI has become more prevalent in the ICUs. Different kinds of data are collected constantly and should be interpreted in an accurate fashion. The key to maximizing AI in the ICU is to find the right balance between data, algorithms, and physicians to ensure that the technical, computational, and clinical needs are targeted.

For individuals, sepsis and mechanical ventilation have been two important aspects where AI has been extensively studied. However, major risks of bias, lack of

generalizability, and poor clinical values imply that AI is far from perfect. AI deployment in ICUs should be more emphasized to facilitate AI development.

More importantly, AI has huge potential in transforming resource allocation in ICUs. The COVID-19 pandemic has given some opportunities to establish such systems and more should be investigated. Ethical concerns must be addressed when designing such AI.

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