A Scoping Review of the Role of Clinical Decision Support Systems in Intensive Care Units during the COVID-19 Pandemic

Zaid O. Olanrewaju,[a,b] Muhammed Faisal,[a,b] Rebecca Randell[a,b]

[a]Faculty of Health Studies, University of Bradford, Bradford, UK
[b]Wolfson Centre for Applied Health Research, Bradford, UK

DOI: 10.25929/ezsh8p05

ABSTRACT

During the COVID-19 pandemic, clinical decision support systems (CDSS) have been increasingly instrumental in reshaping the intensive care unit (ICU) landscape. This paper highlights the importance of CDSS in improving healthcare professionals' decision-making processes by examining their numerous contributions to the management of critically ill patients.

This scoping review comprised information concerning the role of CDSS in ICUs during the COVID-19 pandemic and lessons for the future of public health care (PHC). The identified literature was published during the COVID-19 peak years (2019–2023), retrieved from the Cochrane Library, Embase, Medline, PubMed, CINAHL, Google Scholar and Scopus. A set of predefined inclusion criteria were used, then thematic analysis was applied. The reporting followed the PRISMA guidelines for scoping reviews.

A total of 9 studies were included in the final synthesis (all articles). These studies examined various aspects of the role of CDSS in ICUs during the COVID-19 pandemic. The scoping review was comprehensive and focused on the emerging topic of discussion but lacked risk of bias assessment.

In the midst of the COVID-19 pandemic's unparalleled obstacles, CDSS in ICUs became a vital resource for medical professionals. These technologies help physicians diagnose, treat, and manage COVID-19 patients by using innovative algorithms and real-time data analytics. Early identification, monitoring, timely alarms, and insights into patients' changing clinical status are some of the most crucial functions of CDSS. This capacity was vital in quickly recognising conditions that were getting worse, facilitating quick action, and enhancing patient outcomes.

Additionally, CDSS in ICUs proved effective in therapy guiding, providing evidence-based suggestions for therapeutic approaches. Through the integration of patient information, test findings, and established procedures, these systems enabled tailored and efficient treatment, guaranteeing that medical interventions corresponded with the dynamic course of the illness. Moreover, CDSS helped with risk classification, which enabled medical practitioners to carefully manage resource allocation and customise interventions based on the unique profiles of each patient.

Through the reduction of errors and improvement of patient safety, CDSS was significant in the field of drug management. These technologies met the vital requirement for accuracy in COVID-19 patient care by providing notifications for drug interactions, dosage modifications, and medication administration.
The extensive capabilities that were required in the ICU highlight the revolutionary influence on healthcare delivery that CDSS have. CDSS was invaluable in navigating the challenges of caring critically sick patients in the demanding setting of the global health crisis by integrating evidence-based practices, optimising resource utilisation, and offering real-time decision support.

KEYWORDS

Clinical decision support systems, clinical decision support, patient outcomes, COVID-19, intensive care unit

1. Introduction

In order to optimise the delivery of healthcare, CDSS became essential, especially in intensive care units (ICUs) during the COVID-19 pandemic. Healthcare practitioners can make well-informed decisions about diagnosis, treatment, and management with the help of these technologies that combine medical knowledge with patient data. [1–3] Personalised treatment, risk assessment, and early detection of COVID-19 patients were made possible by CDSS in ICUs through the use of algorithms and data analytics. [3] These solutions improved clinical outcomes, expedited workflows, and supported more effective resource use in critical care settings by offering real-time assistance. This paper will explore the role of CDSS in the ICUs during COVID-19.

2. Background

Decision support systems are used to support business operations and management while CDSS are a variation of a decision supports system using computerised clinical knowledge management to make decision for quality care and patient safety. [4] An overview of some further applications of decision support systems is listed in Table 1.

Table 1: Overview of some applications using decision support systems.

Field	*Example*
Healthcare	Assist healthcare professionals in diagnosis, treatment, and patient management, ensuring evidence-based care delivery
Business and finance	Business support strategic planning, financial analysis, market forecasting, and risk management, aiding in informed decision-making
Supply chain management	Optimise inventory control, logistics, and supply chain operations by analysing data and predicting demand, ensuring efficiency

Agriculture	Aid farmers in crop management, irrigation scheduling, pest control, and predicting crop yields based on weather and soil data
Environmental management	Help in environmental monitoring, resource allocation, and policy planning by analysing ecological data and simulating scenarios
Education	Assist in curriculum planning, student performance analysis, and adaptive learning, enhancing teaching strategies and student outcomes
Transportation and logistics	Optimise route planning, fleet management, and transportation scheduling, reducing costs and improving efficiency
Military and defence	Aid in tactical planning, intelligence analysis, mission planning, and supporting military operations
Marketing and customer relationship management (CRM)	Assist in market segmentation, customer profiling, and personalised marketing strategies based on data analysis
Energy management	Optimise energy distribution, resource allocation, and demand forecasting in the energy sector, promoting sustainability

CDSS are utilised in clinical settings to help physicians, nurses and allied health professional make evidence-based decisions at the right time that improve clinical performance and patient care. [5,6] CDSS find widespread application across various healthcare domains and are commonly administered through electronic patient records. [7] Table 2 lists some of the clinical uses of CDSS in healthcare.

Table 2: Clinical uses of CDSS in healthcare.

- Clinical uses of diagnostic support: Assisting in differential diagnosis by analysing symptoms, patient history, and test results
- Drug interaction and prescription assistance: Alerting healthcare providers to potential drug interactions, allergies, and suggesting appropriate medications
- Therapeutic decision support: Providing guidance on treatment options and protocols based on patient data and evidence-based guidelines
- Chronic disease management: Supporting long-term care plans and monitoring for chronic conditions such as diabetes, hypertension, etc.
- Imaging interpretation: Assisting radiologists in interpreting medical images (e.g., X-rays, MRIs) for accurate diagnosis
- Clinical documentation and reporting: Aiding in accurate and timely documentation of patient information and generating reports
- Alerts and reminders: Notifying healthcare professionals about critical events, overdue tasks, or necessary interventions
- Surgical decision support: Offering guidance in surgical planning, risk assessment, and post operative care

3. Methodology

The scoping review is a literature review conducted to create an overview of the existing published works on the role of CDSS in ICUs during the COVID-19 pandemic. A scoping study was more appropriate than a systematic review, with focused research questions and a strict quality filter, because it is a recent topic and there was a need to evaluate what literature was available. This scoping review followed the methodology developed by Arksey and O'Malley [8] with the adoption of some of the recommendations of Peter et al. [9]

A scoping review of existing literature on the use of CDSS in the ICU was conducted to answer the following three research questions:

1. What types of CDSS were used in ICUs to monitor the COVID-19 pandemic?

2. What were the impacts of the use of CDSS in the ICUs during the COVID-19 pandemic?

3. What are the effects of integrating CDSS with Electronic Patient Records EPR in ICUs during the COVID-19 pandemic?

Review technique

A comprehensive scoping review was implemented to gather information from various sources, including electronic databases, reference lists, and non-traditional or grey literature. The databases of the Cochrane Library, Embase, Medline, PubMed, CINAHL, Google Scholar and Scopus were searched using combinations of the following keywords: *(CDSS or clinical decision support systems)* and *(ICU or intensive care unit or critical care facility or medical crisis unit or critical care units or intensive therapy units or high dependency care or high dependency unit or ITU or HDU)*. The search was conducted from December 2019 up to February 2024. The selection of the articles followed the PRISMA 2020 flow.

To standardise the research thoroughly, this process involved the six essential stages suggested by the Arksey and O'Malley Framework:

A. Identification of the research question

The Levac et al. [10] and Peter et al. [9] school of thought that advocated the inclusion of consultations in scoping reviews was implemented for this review. These consultations are to enable the comprehensiveness and relevance of the review process, thereby validating findings, improving the interpretation of results, and enhancing the applicability of the review findings in real-world settings. Two sets of stakeholders consultations involving staff from three National Health Service (NHS) trusts (provider organisations) in the United Kingdom were conducted to elicit information on the use of technology by the NHS during the COVID-19 pandemic. The first consultation included stakeholders involved in the use of technology in the NHS. A snowball sampling technique was used to include participants for the study. A total of six members of medical personnel participated in the consultation. The second consultation involved stakeholders from three local NHS trusts (provider organisations).

B. Discovery of relevant literature

The articles were first selected based on title and abstract, then the full texts of those that were tentatively relevant were retrieved.

C. Choosing relevant studies

The full texts were then screened using the inclusion criteria for the study in EndNote. Inclusion criteria for this review included all publication types including articles, books, and reviews clearly defining "any technology used in monitoring all aspects of healthcare during COVID-19 outbreak in hospitals"; published and accepted but not yet published review articles, original research articles, meta-analyses, reports and guidelines published in English language; studies on healthcare information technology and healthcare delivery during the COVID-19 pandemic, adoption of technology in the health sector, impact of technology in decision-making process in the health sector during the COVID-19 pandemic, the adoption, use and efficiency of technology during the COVID-19 pandemic that cited technologies used to combat COVID-19. Only literature published since 2019 until February 2024 was included in the study because the pandemic started in December 2019.

D. Mapping out the data

Details of selected papers such as author, year of publication, country of publication, type of publication, the main aim and objective of the study and key findings that are related to the scoping review questions were all recorded. The recorded data was charted and classified using main themes to organise the major findings. A formal quality appraisal was conducted using the JBI appraisal checklist for systematic reviews and research syntheses The reporting of the findings of this review followed the PRISMA-ScR formulated by Tricco et al.[10, 11]

Realist Evaluation

The goal of realist evaluation is to comprehend the intricate interrelationships between these mechanisms and how context affects their operationalisation and result. The formula for this is context + mechanism = outcome. After that, this is shown as a context–mechanism–outcome (CMO) configuration. Realist analysis uses the CMO configuration as its primary structural model. The selected articles were analysed using realist evaluation theory to find the underlying causal mechanisms that explain how the intervention in the use of CDSS in the ICU during the COVID-19 pandemic works, who it benefits, and under what circumstances the focus of realist evaluation is.

4. Results

PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only.

The EndNote software was used to manage the search results, and duplicates were manually eliminated and double-checked. Two steps were taken in the selection of studies: abstract screening and full text evaluation based on the predetermined exclusion and inclusion criteria.

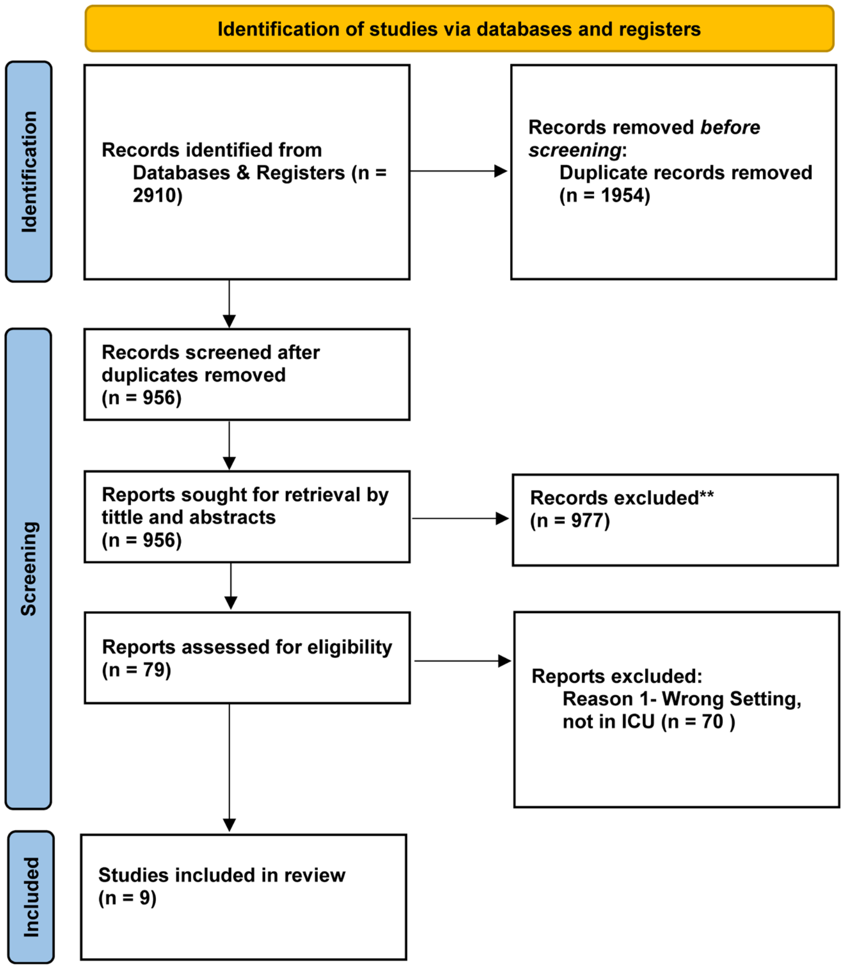

Figure 1. PRISMA Flow diagram of literature search.

At the end of the searches 2,910 articles were retrieved, including 1,954 duplicate articles and 956 unique articles. 977 articles were not eligible based on the inclusion criteria. After further screening, 70 articles out of the remaining 79 were excluded. Reasons for exclusion include: the non-availability of the full text, some articles did not discuss the use of CDSS in monitoring COVID-19 and some records discussed non-ICU use of CDSS during the COVID-19 pandemic. Data were extracted from 9 articles that meet the inclusion criteria (Figure 1).

Study characteristics

Overall, 9 studies were included from the scoping review papers to develop the programme theory and CMOs for the rapid realist review. The main characteristics includes the authors, year, country of origin, and topic of each document. This are listed in table 3 below.

Table 3: Scoping review documents used in the rapid realist review.

	Author and Year	Country	Topic of paper	Study design
1.	Martín-Lázaro et al.[12]	United Kingdom	Clinical decision support systems in critical care during the COVID-19 pandemic	Case study
2.	Sutton et al.[7]	Canada	An overview of clinical decision support systems: benefits, risks, and strategies for success	Literature review
3.	Deif et al.[13]	Thailand	Automated triage system for intensive care admissions during the COVID-19 pandemic using hybrid XGBoost-AHP approach	Quantitative model developed with data from Kaggle online resource to Sirio Libanês, an elite hospital in Brazil
4.	Jansson et al.[14]	Finland	Artificial intelligence for clinical decision support in critical care, required and accelerated by COVID-19	Editorial
5.	Murri et al.[15]	Italy	A real-time integrated framework to support clinical decision making for COVID-19 patients	Quantitative model developed in SAS Software
6.	Karthikeyan et al.[6]	India	Machine learning-based clinical decision support system for early COVID-19 mortality prediction	Quantitative – time series
7.	Shah et al.[16]	USA	Implementation of an anticoagulation practice guideline for COVID-19 via a clinical decision support system in a large academic health system and its evaluation: observational study	Observational study
8.	Moulaei et al.[17]	Iran	Diagnosing, managing, and controlling COVID-19 using clinical decision support systems: A study to introduce CDSS applications	Literature review and questionaire
9.	Ameri et al.[18]	Iran	Clinical decision support systems (CDSS) in assistance to COVID-19 diagnosis: A scoping review on types and evaluation methods	Scoping review

A. Types of CDSS in the ICU

CDSS applications are categorised in 4 classes: “diagnosis”, ”medication”, “monitoring”, and “health services. [17] CDSS can then be further categorised based on five distinct characteristics including mode of advice provided, style of communication, core decision-making process system function, human computer interaction and underlying model for giving advice. [7,19]

In a scoping review of the usefulness and efficacy of CDSS in identifying and diagnosing COVID-19, the results showed that the CDSS based on machine learning (ML) was the most often used approach for this purpose, ahead of those based on expert systems (ES). It was discovered that knowledge-based CDSS (ES) and non-knowledge-based CDSS (ML) both contributed significantly to the accurate diagnosis of COVID-19. [18]

B. Benefits of CDSS during the COVID-19 pandemic

CDSS have always been useful in hospitals for supporting clinical decisions, yet healthcare professionals have never used it in such proportions as demanded during the COVID-19 pandemic. This led to some innovative CDSS applications that were flexible, saved time, enabled collaboration, and were target-driven while allowing clinicians to make better decisions. [2,17]

CDSS were used as evidence-based tools [20,21] for early mortality prediction, [6] severity risk prediction and triage on admission, [22] elective operations resource utilisation, [23] deployed to direct hospital frontlines and healthcare administrators in making informed decisions about patient care and hospital volume plan. [24] The COVID-19 pandemic prompted activities to collect and consolidate patient data, yet the substantial volume of newly acquired data necessitated ongoing quality assurance measures to guarantee the attainment of desired outcomes. [24]

CDSS have also been used in emergency departments where it has been very impactful in bringing about significant improvement in care delivery. [25] CDSS are known to permit non-clinical staff along with clinical staff, to conduct thorough clinical assessments of phone callers to emergency and urgent care services. [26,27]

In a study that addressed the challenge of exceeding ICU and ventilator capacity during the COVID-19 pandemic despite healthcare systems prioritizing admissions, CDSS was used to create a classifier model predicting ICU necessity based on 38 commonly used clinical variables such as blood test, liver function , kidney function , vital signs , blood gas analysis, etc. and also to allocate importance to these variables using the Shapley value and weighting them through the analytic hierarchy process (AHP), facilitating the prioritisation of patients for ICU admission based on risk levels. [13] AHP is a time-constrained decision-making model, while the Shapley value aids interpretability in predictive models [28] and constitutes the average marginal contribution of a feature value across all possible coalitions. [29]

Programme theory development

Before the onset of the COVID-19 pandemic, a considerable number of up to 20 million individuals annually necessitated ICU admission and mechanical ventilation (MV). In response to the pandemic, the demand for critical care services has undergone an exponential increase. Faced with this "new reality", ICUs and emergency departments (EDs) underwent a redesign. [14]

Table 4 shows the context, mechanisms, outcomes CMOs constructed for this study taken from the 9 documents that best illustrate CMO relationships. [30–32]

The use of CDSS in ICUs

Intervention	**Context**	**Mechanism/Resource**	**Outcome**
CDSS was used in admitting to the ICU	The input of triage committees are timely but traditional tools such as Sequential Organ Failure Assessment SOFA are obsolete	There was an urgent need for a COVID-19 disease severity assessment that can assist in critical care in resource allocation for patients at risk for severe diseases	CDSS reduced the burden of decision-making placed on clinicians
The referral of a patient for ICU care triggered complex triage (prioritisation) decision-making when ICU beds are limited	CDSS was expected to increase objectivity and transparency in triage decision-making, and helps to enhance consistency between doctors both within and across ICUs	The complexity of the decision-making process and the multiple factors that require careful consideration requires the final decisions to be made by an experienced ICU doctor.	Junior doctors be trained to read CDSS for assistance to guide and enhance consistent and justifiable decision-making in uncontrollable circumstances when experienced doctors are not available
The sudden increase in patients with severe COVID-19 has obliged doctors to make admissions to ICUs in healthcare practices where capacity is exceeded by the demandl.	The CDSS is proposed to aid healthcare professionals in prioritising patients infected with COVID-19 based on the results of biological laboratory examinations, provide the desired intensive care facilities, and to manage patients' health conditions by indoor healthcare providers	CDSS classified patients in a dataset into patients with COVID-19 who need ICU admission and those who do not	The CDSS criteria weights determined which patients will use the ICU first during emergency or limited-resource situation
Over 20 million people annually require ICU admission and mechanical ventilation	Geolocated critical care demands prediction, optimal hospital resource planning, and intelligent patient flow management with decision support algorithms, which can be achieved by integrating real-time clinical data with population statistics and health interventions	Safe, effective, efficient, and ethical clinical management of COVID-19 patients in ICUs urgently requires integrating AI capabilities into CDSS at the patient bedside	Advances in the CDSS direction of predicting the entire temporal evolution of a patient used for developing personalised patient management and treatment plans

The applications of a CDSS in the diagnosis, management, and control of COVID-19	Identify general, basic knowledge of the design and implementation of clinical decision support systems in the real world to prevent irreversible complications and even many persons' deaths	Classification of patients based on the severity of complications, signs and symptoms, global COVID-19 protocol, and CT images taken from damaged lung tissue (for hospitalization in the wards, ICUs, or home quarantine)	CDSS applications were categorised in 4 classes: "diagnosis", "medication", "monitoring", and "health services"
The high number of people with COVID-19 admitted to emergency rooms, general wards and ICUs critically stressed hospitals	Extensive amounts of data were quickly available for data monitoring, data analysis and clustering	Predictive models identified clinical criteria and laboratory values to safely allocate a person to common wards or to be discharged at home or to be de-isolated when probability of a COVID-19 diagnosis is poor	CDSS provided the opportunity to realise a real-world, readily available, interactive dashboard and to build sophisticated and advanced predictive models
The sudden spike in the number of COVID-19 infections and high mortality rates have put immense pressure on the public healthcare systems	It is crucial to identify the key factors for mortality prediction to optimize patient treatment strategy	Various ML models (neural networks, logistic regression, XGBoost, random forests, SVM, and decision trees) have been trained and their performance compared to determine the model that achieves consistently high accuracy across the days that span the disease	The best performing method using XGBoost feature importance and neural network classification predicts with an accuracy of 90%
Study evaluated strategies for the rapid development, implementation, and evaluation of clinical decision support (CDS) systems supporting guidelines for diseases with a poor knowledge base, such as COVID-19	Developed an anticoagulation clinical practice guideline (CPG) for COVID-19	Institutional experience demonstrated that adherence to the institutional clinical practice guideline (CPG) delivered via the clinical decision support (CDS) system resulted in improved clinical outcomes for patients with COVID-19	CDSS systems proved to be an effective means to rapidly scale a CPG across a heterogeneous healthcare system
Identifying and introducing CDSS applications to manage, control, and monitor the patients infected with COVID-19	CDSS with alert capabilities or recommendations for clinicians permitted decisions based on the known side effects of medications, their interactions, and potential contraindications	CDSS implementation has been associated with decreased unnecessary treatments and diagnostic costs, streamlined diagnostic processes, enhanced clinical performance, and improved patient-related outcomes.	The proactive identification, diagnosis, and treatment facilitated by CDSS contribute significantly to preventing the further spread of COVID-19

C. Evaluation of the integration of CDSS with EPR

Studies on clinical decision support systems (CDSS) based on the integration with electronic patient records (EPR) in the ICU revealed high accuracy in decision making, [17,18] however, questions about replacing these systems as clinician assistants in decision-making were raised due to concerns about the novelty and biases in the dataset.

Clinicians profited from an electronic patient record (EPR) that was properly deployed because it increased their productivity, streamlined their workflows, and gave them more visibility into their patients.

5. Discussion

Clinical decision support systems (CDSS) have been instrumental in alleviating the decision-making burden on clinicians, particularly in situations where experienced doctors are unavailable, thus facilitating consistent and justifiable decisions. It is imperative that junior doctors receive adequate training to effectively use CDSS, especially in navigating uncontrollable circumstances. Moreover, the determination of patient prioritisation during emergencies or limited-resource situations relies heavily on the criteria weights established within the CDSS framework.

Advancements in CDSS technology have enabled the prediction of patient outcomes, which in turn facilitates the development of personalised management and treatment plans. The applications of CDSS are typically categorised into distinct classes such as diagnosis, medication, monitoring, and health services, underscoring their multifaceted utility within healthcare settings. Furthermore, the potential of CDSS extends to the creation of interactive dashboards and the construction of sophisticated predictive models, thereby enhancing the efficacy of real-world clinical decision-making processes.

It is accepted that although EPR are seen to have valuable advantages, there remains significant capacity to improve clinicians' interaction and satisfaction with these systems. Some of the inadequacies identified by clinicians include human computer interaction – usability, systems navigation and information visualisation. [33] CDSS play a positive impact in medication safety and cost savings, but engagement of relevant stakeholders was deemed critical for the initial and sustained use of the technology. [34] The level of engagement with a mobile clinical decision support system by junior physicians was discovered to be reduced due to a number of cultural, institutional and individual barriers. [35]

CDSS developers must collaborate with end users for a clear understanding of the clinic workflow pathway and provide users training to reduce the immense occurrence of false alerts which causes critical decision alerts to be ignored. There must be collaboration and synergy between hospitals and vendors/producers of CDSS solutions. [36]

In conformity with other studies where CDSS are known to have been integrated with EPR despite interoperability issues to increase the acceptance by physicians there must adequate training and users input during development. [37] The need for CDSS systems development, procurement, and implementation to be tailored to the needs of users is regarded as user 'pull'. [36]

6. Conclusion

Clinical decision support systems (CDSS) exert a significant impact within intensive care units (ICUs), notably in furnishing precise recommendations for patient management. The integration of CDSS with electronic patient records (EPR) amplifies its benefits in the ICU setting, thereby augmenting patient care and healthcare management. Ensuring seamless integration into EPR is imperative for CDSS, given the pivotal role of EPR as the principal data repository within the ICU.

The collective findings underscore the importance of leveraging the combined strengths of CDSS and EPR for improved decision-making, enhancing patient outcomes and healthcare efficiency in the ICU setting. Future research and implementation efforts should continue to explore and optimize this synergistic relationship for maximum benefit.

To enhance usability, ICUs should prioritise the implementation of explainable systems, adhering to the principles of explainable AI, and ensure adequate training and education for junior clinicians. This approach not only promotes transparency in decision-making processes but also empowers clinicians with the necessary knowledge and skills to effectively use and interpret CDSS within critical care settings.

References and notes

[1] Chen J, Lowin M, Kellner D, et al. Designing Expert-Augmented Clinical Decision Support Systems to Predict Mortality Risk in ICUs. *KI - Künstliche Intelligenz*. 2023.

[2] Laxar D, Eitenberger M, Maleczek M, Kaider A, Hammerle FP, Kimberger O. The influence of explainable vs non-explainable clinical decision support systems on rapid triage decisions: a mixed methods study. *BMC Medicine.* 2023;21(1):359.

[3] Chen Z, Liang N, Zhang H, et al. Harnessing the power of clinical decision support systems: challenges and opportunities. *Open Heart*. 2023;10(2).

[4] Safdari R, Rezayi S, Saeedi S, Tanhapour M, Gholamzadeh M. Using data mining techniques to fight and control epidemics: A scoping review. *Health Technol (Berl)*. 2021:1-13.

[5] Souza-Pereira L, Pombo N, Ouhbi S, Felizardo V, Garcia N. Clinical decision support systems for chronic diseases: A Systematic literature review. *Computer Methods and Programs in Biomedicine.* 2020;195:105565.

[6] Karthikeyan A, Garg A, Vinod PK, Priyakumar UD. Machine Learning Based Clinical Decision Support System for Early COVID-19 Mortality Prediction. *Frontiers in Public Health.* 2021;9(475).

[7] Sutton RT, Pincock D, Baumgart DC, Sadowski DC, Fedorak RN, Kroeker KI. An overview of clinical decision support systems: benefits, risks, and strategies for success. *NPJ Digit Med.* 2020;3:17.

[8] Arksey H, O'Malley L. Scoping studies: towards a methodological framework. *International Journal of Social Research Methodology.* 2005;8(1):19-32.

[9] Peters MDJ, Marnie C, Tricco AC, et al. Updated methodological guidance for the conduct of scoping reviews. *JBI Evid Synth.* 2020;18(10):2119-2126.

[10] Tricco AC, Lillie E, Zarin W, et al. A scoping review on the conduct and reporting of scoping reviews. *BMC Med Res Methodol.* 2016;16(1):15.

[11] Khalil H, Peters MDJ, Tricco AC, et al. Conducting high quality scoping reviews-challenges and solutions. *Journal of Clinical Epidemiology.* 2021;130:156-160.

[12] Martín-Lázaro J, Kelly J, Álamo P. Clinical Decision Support Systems in Critical Care during Covid-19. *Clinical Medical Reviews and Reports.* 2021;Clinical Medical Reviews & Reports:64.

[13] Deif MA, Solyman AAA, Alsharif MH, Uthansakul P. Automated Triage System for Intensive Care Admissions during the COVID-19 Pandemic Using Hybrid XGBoost-AHP Approach. *Sensors.* 2021;21(19):6379.

[14] Jansson M, Rubio J, Gavaldà R, Rello J. Artificial Intelligence for clinical decision support in Critical Care, required and accelerated by COVID-19. *Anaesth Crit Care Pain Med.* 2020;39(6):691-693.

[15] Murri R, Masciocchi C, Lenkowicz J, et al. A real-time integrated framework to support clinical decision making for covid-19 patients. *Computer Methods and Programs in Biomedicine*. 2022;217:106655.

[16] Shah S, Switzer S, Shippee ND, et al. Implementation of an Anticoagulation Practice Guideline for COVID-19 via a Clinical Decision Support System in a Large Academic Health System and Its Evaluation: Observational Study. *JMIR Med Inform*. 2021;9(11):e30743.

[17] Moulaei K, Bahaadinbeigy K. Diagnosing, Managing, and Controlling COVID-19 using Clinical Decision Support Systems: A Study to Introduce CDSS Applications. *J Biomed Phys Eng*. 2022;12(2):213-224..

[18] Ameri A, Ameri A, Salmanizadeh F, Bahaadinbeigy K. Clinical decision support systems (CDSS) in assistance to COVID-19 diagnosis: A scoping review on types and evaluation methods. *Health Sci Rep.* 2024;7(2):e1919.

[19] Kim S, Kim EH, Kim HS. Physician Knowledge Base: Clinical Decision Support Systems. *Yonsei Med J*. 2022;63(1):8-15.

[20] McRae MP, Dapkins IP, Sharif I, et al. Managing COVID-19 With a Clinical Decision Support Tool in a Community Health Network: Algorithm Development and Validation. *J Med Internet Res.* 2020;22(8):e22033.

[21] McRae MP, Simmons GW, Christodoulides NJ, et al. Clinical decision support tool and rapid point-of-care platform for determining disease severity in patients with COVID-19. *Lab on a Chip.* 2020;20(12):2075-2085

[22] Wu G, Yang P, Xie Y, et al. Development of a Clinical Decision Support System for Severity Risk Prediction and Triage of COVID-19 Patients at Hospital Admission: an International Multicenter Study. *European Respiratory Journal.* 2020:2001104.

[23] Goldstein BA, Cerullo M, Krishnamoorthy V, et al. Development and Performance of a Clinical Decision Support Tool to Inform Resource Utilization for Elective Operations. *JAMA Network Open*. 2020;3(11):e2023547-e2023547.

[24] Debnath S, Barnaby DP, Coppa K, et al. Machine learning to assist clinical decision-making during the COVID-19 pandemic. *Bioelectronic Medicine.* 2020;6(1):14.

[25] Flores E, Salinas JM, Blasco Á, et al. Clinical Decision Support systems: A step forward in establishing the clinical laboratory as a decision maker hub - A CDS system protocol implementation in the clinical laboratory. *Computational and Structural Biotechnology Journal*. 2023;22:27-31.

[26] Hak F, Guimarães T, Santos M. Towards effective clinical decision support systems: A systematic review. *PLOS ONE.* 2022;17(8):e0272846.

[27] Guangyao W, Pei Y, Yuanliang X, et al. Development of a Clinical Decision Support System for Severity Risk Prediction and Triage of COVID-19 Patients at Hospital Admission: an International Multicenter Study. *European Respiratory Journal.* 2020:2001104.

[28] Leal JE. AHP-express: A simplified version of the analytical hierarchy process method. *MethodsX*. 2020;7:100748.

[29] As I, Basu P, Talwar P. Artificial Intelligence in Urban Planning and Design. In: As I, Basu P, Talwar P, eds. *Artificial Intelligence in Urban Planning and Design.* Elsevier; 2022:381-385.

[30] Pawson R, Manzano-Santaella A. A realist diagnostic workshop. *Evaluation.* 2012;18(2):176-191.

[31] Pawson R, Tilley N, Tilley N. *Realistic evaluation.* sage; 1997.

[32] De Weger E, Van Vooren NJE, Wong G, et al. What's in a Realist Configuration? Deciding Which Causal Configurations to Use, How, and Why. *International Journal of Qualitative Methods.* 2020;19:1609406920938577.

[33] Bouamrane M-M, Mair FS. A study of general practitioners' perspectives on electronic medical records systems in NHSScotland. *BMC Medical Informatics and Decision Making.* 2013;13(1):58.

[34] Jeffries M, Salema NE, Laing L, et al. The implementation, use and sustainability of a clinical decision support system for medication optimisation in primary care: A qualitative evaluation. *PLoS One*. 2021;16(5):e0250946.

[35] Patel R, Green W, Shahzad MW, Larkin C. Use of Mobile Clinical Decision Support Software by Junior Doctors at a UK Teaching Hospital: Identification and Evaluation of Barriers to Engagement. *JMIR mHealth uHealth*. 2015;3(3):e80.

[36] Cresswell KM, Lee L, Slee A, Coleman J, Bates DW, Sheikh A. Qualitative analysis of vendor discussions on the procurement of Computerised Physician Order Entry and Clinical Decision Support systems in hospitals. *BMJ Open*. 2015;5(10):e008313.

[37] Al-Garni BM. Analysis and Review of Prescribing Clinical Decision Support System within the Context of Nhs Secondary Sector. *LIFE: International Journal of Health and Life-Sciences*. 2018;4(3):60-71.