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A systematic review on machine learning algorithms to predict the length of stay for COVID-19 patients

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A B S T R A C T

Introduction: Managing resources is one of the most important challenges that healthcare providers worldwide face during the COVID-19 pandemic. In recent years, machine learning has been developed to provide valuable help in predicting disease and estimating the duration of their stay. This study aimed to identify the machine learning models for predicting length of stay in COVID-19.

Material and Methods: Online databases, including Scopus, PubMed, Web of Science, and Science Direct, were searched, and a hand search through Google Scholar and grey literature was done up to August 2023 and updated in December 2023 to identify articles to find all relevant studies. To manage the process and check the quality of included articles PRISMA guidelines and CASP checklist were used and data was extracted using a data extraction form.

Results: Among all 489 research articles, 10 studies met the inclusion criteria. The best models reported in the included articles were random forest (n=3), gradient boosting (n=2), XGBoost (n=2), SVM (n=1), KNN (n=1), and DataRobot (n=1). Except one of the studies that used quantitative modeling and reported MSE and MAE as evaluation criteria, other studies used qualitative modeling and reported accuracy, specificity, and F1-score. The focus of the included articles was on the general and ICU departments as the important resources in the hospital and emphasized the use of machine learning to predict the length of stay.

Conclusion: The results of this systematic review showed that a data mining approach and using a machine learning algorithm can help to manage the critical resources of the hospital especially when we are faced with a pandemic disease like COVID-19.

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INTRODUCTION

During the COVID-19 pandemic, healthcare systems worldwide were overwhelmed by the sudden influx of patients. Meanwhile, countries have faced numerous challenges in keeping the health system responsive and capable of providing essential health services [1]. COVID-19 has exposed health systems to various challenges that have led to shortages of hospital resources [2, 3].

Increasing the length of stay (LOS) is one of the important challenges that most hospitals have faced during this pandemic [4]. LOS is a given estimation by the hospital to the patient regarding the amount of time the patient is most likely to spend in the hospital considering his/her condition. The duration is affected by diagnosis, severity of the condition, patient constitution, and a variety of other factors. Estimating the LOS at the time of admission can help to predict the patient's discharge date that aids in planning critical medical operations [5, 6]. LOS is also regarded as a reliable proxy for measuring hospital resource utilization [7] and as an important indicator for evaluating the effectiveness of hospital management [8, 9].

The COVID-19 pandemic highlighted the critical importance of bed capacity management for all diseases, especially in outbreaks requiring rapid implementation of action plans [10]. The challenge of managing the enormous demand for hospitalization during the pandemic, which exceeded the capacity of health facilities, raised the need for skillful integration of scarce data and ambiguous indicators [11]. Therefore, predicting a patient's LOS at the time of admission has great importance in developing the logistics planning strategy of the hospitals [12, 13].

Machine learning, a sub-branch of artificial intelligence (AI), serves as an efficient means to facilitate informed decision-making in the healthcare sector by autonomously discerning actionable patterns from extensive structured datasets [14]. Machine learning techniques are widely known as a promising analytical approach and they are established tools for creating predictive models and extracting valuable insights implicitly from datasets [15-17]. In the contemporary landscape, machine learning has significant importance as a scientific methodology proficient in accurately forecasting probabilities and corresponding risk rates across diverse phenomena and events [18, 19]. The prevalence of machine learning methods and models has expanded substantially, encompassing various realms in the battle against COVID-19 and predictions related to disease transmission, mortality, and vaccine development [20].

In general, machine learning is used for three main purposes, including data description, prediction based on previous data, and prescribing actions based on the two previously mentioned types [21]. Machine learning in different classifications helps physicians and other healthcare providers in predicting, describing, diagnosing, treating, and taking preventive measures based on data elements with different methods [7]. Many classification algorithms in the analysis of clinical data such as artificial neural networks (ANN), random forest algorithm, k-nearest neighbors (KNN), support vector machine (SVM), decision tree (DT), gradient boosting (GB), XGBoost, and Naive Bayes (NB) are used [22].

Several studies have been conducted using these algorithms to predict the length of stay of COVID-19 patients. For example, Afrash et al. [23], using the records of 1225 hospitalized patients, predicted the risk of mortality in COVID-19 patients with the help of machine algorithms in Iran. In this study, the researchers found that the SVM algorithm is the best algorithm with a mean accuracy of 99.5%, mean specificity of 99.7%, mean sensitivity of 99.4%, and a standard deviation of 1.2 for predicting LOS. This algorithm with reasonable accuracy and certainty potentially facilitates hospital bed management, turnover, and optimized resource allocation. Alabbad et al. [9], in Saudi Arabia, presented a machine algorithm model to predict the length of stay of COVID-19 patients in ICU beds. Researchers used a dataset of 895 patients and 4 algorithms: random forest (RF), gradient boosting (GB), extreme gradient boosting (XGBoost), and ensemble models. The conducted experiments show that LOS in the ICU can be predicted with the highest accuracy by applying the RF model with an accuracy of 94.16%. In addition, in terms of the contributor factors to the length of stay in the ICU, correlation results showed that age, C-reactive protein (CRP), and nasal oxygen support days are the top related factors.

Another study conducted by Ozbilen et al. [24], presented a machine-learning model that predicted the length of stay of COVID-19 patients in the hospital. The study was conducted using 118 adult patients admitted to the hospital with a diagnosis of COVID-19 in Turkey. The authors used seven key variables, age, gender, length of hospitalization, c-reactive protein, ferritin, lymphocyte count, and the COVID-19 reporting and data system (CORADS), to develop a machine learning model aimed at predicting the LOS in a given context. The KNN model produced the best results among the various models. As per the model, the evaluation outcomes for the estimation of hospitalizations lasting for five days or less and those exceeding five days are as follows: The accuracy was 0.92, and the F1-Score was 0.89.

Since no study has investigated the effectiveness of machine learning models in predicting the length of stay of COVID patients, therefore, this study investigated machine learning algorithms to predict the length of stay of COVID-19 patients.

MATERIAL AND METHODS

Protocol

This systematic review follows the PRISMA statement for systematic reviews. Moreover, the critical appraisal skills program (CASP) checklist was used to help the readers make sense of this qualitative research.

Paper resources

Online databases, including Scopus, PubMed, ISI Web of Science, and Science Direct, were searched, and a hand search through Google Scholar and grey literature was done up to August 2023 and updated in December 2023 to identify articles that developed a model of machine learning algorithms in predicting the LOS for COVID-19 patients.

Search strategy

To organize the search systematically, the search terms around three expressions were grouped:

"Machine Learning", "Length of Stay (LOS)", and "COVID-19". Further elaboration of the three expressions used to find eligible articles could be seen in Table 1. The terms within each expression were a mix of medical subject headings (MeSH) terms and synonyms. AND operator was applied Between each expression and OR operator between each MeSH terms and its synonyms.

Inclusion and exclusion criteria

This study focused on machine learning models used to predict the LOS for COVID-19 patients. The focus was on studies that presented machine learning algorithms that were relevant for predicting the length of stay. It should be mentioned that the studies that predicted the LOS for other diseases were excluded from this research. The studies whose full text was unavailable or was not in English were excluded as well. Finally, studies were excluded if they had not undergone a peer-review process.

Table 1: Search Strategy

Expression 1 (Machine Learning)	Expression 2 (Length of Stay)	Expression 3 (Covid-19)
Machine learning OR Transfer Learning OR Deep Learning OR Artificial Intelligence OR Data Mining	LOS OR Length of Stay OR Stay Length OR Hospital Stay OR Hospitalization time	COVID-19 OR COVID 19 OR SARS-CoV-2 Infection OR SARS CoV 2 Infection OR Coronavirus Disease 2019 OR SARS Coronavirus 2 Infection OR COVID-19 Pandemic

Study selection and data extraction

OneNote was used to manage the included articles. At first, all duplicate references were removed. Titles and abstracts of the selected papers were read to find the eligible articles based on the inclusion and exclusion criteria. The full texts of the remaining articles were studied to extract the required data. The extracted data included authors, publishing year, country, machine learning model and algorithm, sample size, type of data, Location of stay, Model evaluation metrics, and results of the model.

To reduce bias during the selection and reviewing process, the author and one of the co-authors, went through each article systematically, discussed the scope of each article, and decided whether an article was relevant in proportion to the present systematic literature review. The included machine learning models from the studies were subsequently described and classified according to the selected variables. The studies were classified in three ways: 1) type of machine learning model, 2) the location of stay in hospital, and 3) the evaluation metrics of the model.

RESULTS

The flowchart of the article selection process in the systematic literature review is shown in Fig 1. Systematic searches led to the identification of 489 articles. Before starting the preliminary screening process of titles and abstracts, 317 duplicates were removed; hence, 172 records remained to be screened. The screening process followed the inclusion and exclusion criteria as explained in the method section, leaving 22 articles for full-text review. There were 12 articles excluded based on the full-text review process; The final number of studies included in the systematic review was 10.

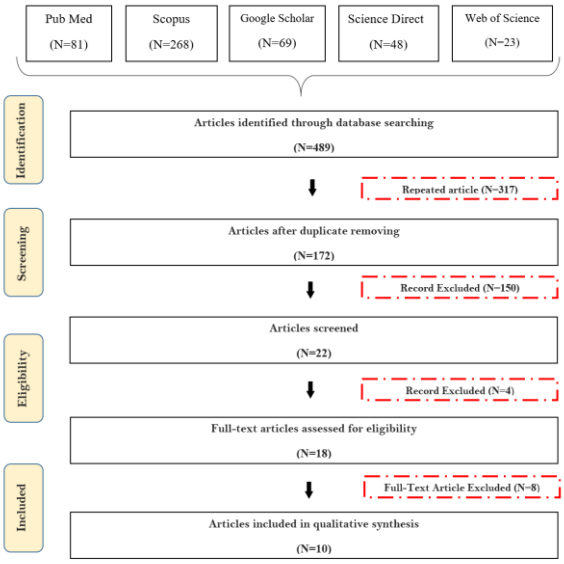

Fig 1: Flow diagram of the article selection process

The included papers in this systematic review, along with information from each paper that was the target of this systematic review, are demonstrated in Table 2. In this table, it is clear that the purpose of each of the studies included in the systematic review was focused on which department of the hospital. Also, the algorithm used to analyze that study has been extracted.

The distribution of the included studies based on the targeted stay location in the hospital is demonstrated in Fig 2 and the geographical distribution of the studies is shown in Fig 3 as well.

Table 2 shows that Demographic, clinical, and laboratory data have been used in almost all the included studies. The general section of the hospital has been more interested in studies, and then the focus of studies has been on ICU. Among machine learning algorithms, Ensemble algorithms such as

Random Forest, Gradient Boosting, and XGBoost have been used the most.

DISCUSSION

Predicting the duration of hospitalization of COVID-19 patients in the hospital is critical for planning and predicting the use of hardware and human resources. On the other hand, data mining and machine learning algorithms are very powerful tools for this category of predictions. Extensive studies were conducted in this field during the COVID-19 pandemic, which was systematically reviewed in this study.

Table 2: Data extracted of selected articles

Authors	Year/Country	Data type	Best ML algorithms	Sample size	Location of stay	Evaluation metrics*
Afrash et al.	2023/Iran	Demographics Clinical Laboratory	SVM	1225	ICU & General Section	Acc: 95.147% Spe: 95.112% Sen: 95.183%
Alabbad et al.	2022/ Saudi Arabia	Clinical Demographics	Random Forest	895	ICU	Acc: 93.81% Sen: 93.79% Spe: 93.81% F1: 93.78%
Askari et al.	2022/Iran	Demographics Clinical Laboratory	Gradient Boosting	12300	General Section	Acc: 73.51%
Ebinger et al.	2021/ USA	Demographics Clinical Laboratory	DataRobot	966	General Section	AUC: 81% Sen: 93% Acc:76% F1: 78% Spe:63% Pre:67%
Etu et al.	2022/ USA	Demographics Clinical Laboratory	Gradient Boosting	3301	Emergency Department	Pre: 85% Rec: 92% F1: 88% AUC: 93% Acc: 85%
Olivato et al.	2022/ Italy	Demographics Clinical Laboratory	XGBoost	6000	ICU & General Section	Acc: 76% Pre: 76: F1: 76% Rec: 76% AUC: 76%
ÖZBİLEN et al.	2023/Turkey	Demographics Clinical Laboratory	KNN	118	General Section	Acc:92% F1: 89%
Saadatmaet al.	2022/Iran	Demographic Chronic Comorbidities Symptoms Vital signs Laboratory	XGBoost	963	ICU & General Section	Acc: 82% Sen: 88% Spe: 60%
Samy et al.	2023/India	Demographic Clinical Laboratory	Random Forest	58,976	ICU	Acc: 89%
Xu et al.	2022/USA	Demographics Clinical Laboratory	Random Forest	42,209	General Section	MSE: 21.185 MAE: 1.877 MRE: 0.972

* ACC=Accuracy; Spe=Specificity; Sen=Sensitivity; AUC=Area under the curve; F1=F1-Score; Pre=Precision; Rec=Recall;

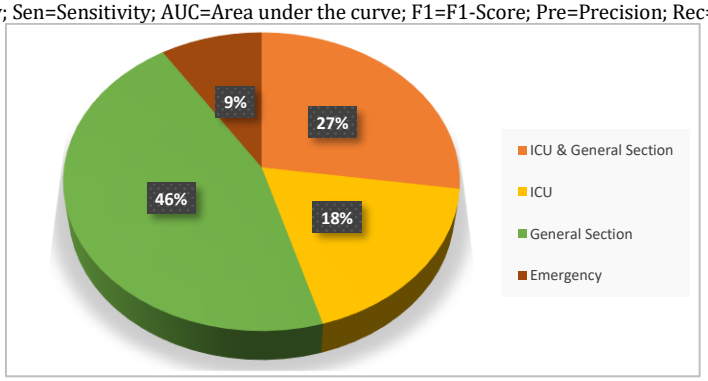

Fig 2: Distribution of the included studies based on targeted stay location in the hospital

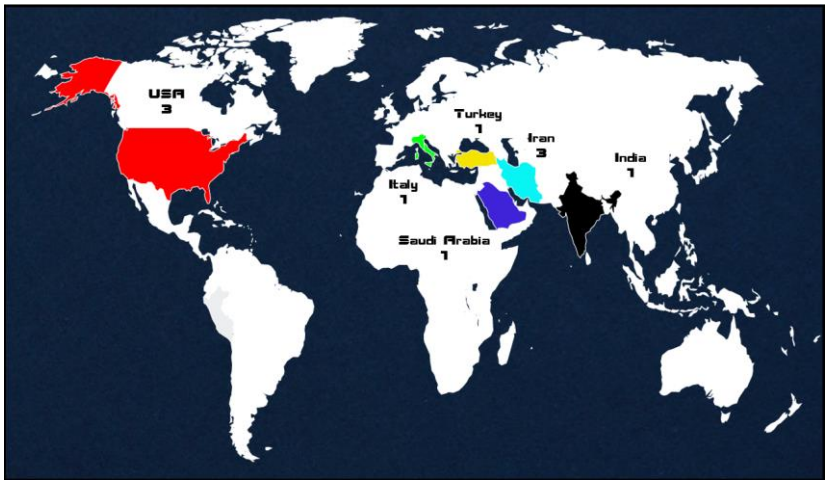

Fig 3: Geographical distribution of the included studies

In this systematic review of machine learning models related to the length of stay for COVID-19 patients, we identified and critically evaluated prediction models described in 10 studies. Nine [4, 23-30] of the prognostic models are qualitative and tried to predict the length of stay for COVID-19 patients in the shape of "Short" or" Long" and only one [31] of them predict the length of stay quantitatively. In the qualitative studies evaluation metrics for qualitative modeling such as accuracy, F1-score, specificity, sensitivity, and AUC have been reported and for the quantitative ones, the evaluation metrics were MAE, MSE, and MRE. The qualitative approach may be suitable for patients who are hospitalized in the general section of the hospital, but for the sections with limited and critical resources such as ICU, it is necessary to have quantitative prediction models and accurately predict the length of stay of the patient. Although this problem can be resolved by determining the appropriate intervals for "short" and "long" classes or using more classes for different time intervals, having a quantitative prediction model can help manage hospital resources, especially in critical departments.

According to the modeling approach presented in the studies included in this study, four articles [24, 26, 27, 31] have studied the general department of the hospital, three studies [23, 28, 29] have targeted the general department of the hospital and the ICU simultaneously, one study [4] related to the emergency department and two studies [25, 30] were related to the ICU department. The only study [31] with quantitative modeling was associated with the hospital's general department. Among machine learning algorithms, Ensemble algorithms such as Random Forest, Gradient Boosting, and XGBoost have been used the most. In the only reviewed quantitative study [31], a random forest algorithm has been used.

There were some limitations in this systematic review. Firstly, unpublished and non-English studies were not included in this review. Secondly, heterogeneities between studies prevented the conducting of a meta-analysis. Finally, there was no standard for the feature selection or the dataset in the reviewed studies. Although the mentioned limitations may have affected the quality of the study the current review's findings provide crucial recommendations for further research. The most important recommendation for future research is that they should focus on implementing a standard dataset to predict the length of stay quantitatively.

CONCLUSION

This Systematic review provides evidence of how to predict the LOS for COVID-19 patients and compare them based on some criteria. This study demonstrated that although predicting the LOS in the hospital is quantitative modeling, almost all studies in this field have been qualitative modeling. This may make it difficult to use the results of these studies in resource management in the critical departments of the hospital. However, because LOS is one of the most important and influential metrics in evaluating the performance and quality of healthcare services and proper resource planning, presenting LOS prediction models can be extremely effective in bed management and decision-making by directly influencing the optimal allocation of medical resources. Generally, various machine learning algorithms in the healthcare industry can be used to address some of the uncertainties in LOS prediction. These preliminary findings support further research into implementing machine learning models as a platform for hospital resource management.

AUTHOR'S CONTRIBUTION

All authors contributed to the literature review, design, data collection and analysis, drafting the manuscript, read and approved the final manuscript.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this study.

FINANCIAL DISCLOSURE

No financial interests related to the material of this manuscript have been declared.

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