Research & Reviews: Journal of Clinical and Medical Case Studies

Research Progress of Artificial Intelligence Technology in COVID-19

Jijin Yang[1],Yan Liang[1], Xiaohua Wang[2]*

[1]Department of Medicine, Affiliated Hospital of Zunyi Medical University, Guizhou Zunyi, China

[2]Department of Medicine, School of Medical Information Engineering, Guizhou Zunyi, China

Review Article

Received: 19-Mar-2023, Manuscript No. JCMCS-23-92242; **Editor assigned:** 22-Mar-2023, Pre QC No. JCMCS-23-92242 (PQ); **Reviewed:** 05-Apr-2023, QC No. JCMCS-23-92242; **Revised:** 12-Apr-2023, Manuscript No. JCMCS-23-92242 (R); **Published:** 20-Apr-2023, DOI: 10.4172/J Clin Med Case Stud.8.2.001.

***For Correspondence:**

Dr. Xiaohua Wang, Department of Medicine, School of Medical Information Engineering, Guizhou Zunyi, China

E-mail: 350031712@qq.com

Citation: Wang X, et al. Research Progress of Artificial Intelligence Technology in COVID-19. J Clin Med Case Stud. 2023;8:001.

ABSTRACT

The ongoing COVID-19 pandemic continues to pose a grave danger to both human lives and the broader functioning of society. In response, healthcare organizations have increasingly turned to the powerful tools of Artificial Intelligence (AI) to tackle the complex challenges posed by the virus. In light of the overwhelming burden placed on the healthcare system during the COVID-19 pandemic, researchers have developed a broad range of AI algorithms and models to aid in clinical diagnosis, epidemic prediction, and clinical treatment. This study provides a comprehensive overview of the latest advancements in AI research in COVID-19, covering four key areas: auxiliary diagnosis and screening, auxiliary clinical therapy, prediction of disease severity and patient prognosis, and epidemic trend prediction. The ultimate aim of this study is to serve as a valuable resource for managing epidemics and informing effective prevention and treatment strategies for future outbreaks.

Keywords: Artificial intelligence; Machine learning; COVID-19; Disease prevention and control; Respiratory distress syndrome

INTRODUCTION

The newly discovered human coronavirus, responsible for the COVID-19 outbreak, has been identified as Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-COV-2). Clinical symptoms of the disease include fever, dry cough, fatigue, and respiratory distress. In severe cases, COVID-19 can lead to rapid onset of multiple organ failure, metabolic acidosis, septic shock, coagulation dysfunction, and acute respiratory distress syndrome [1]. The sudden and unforeseen outbreak of COVID-19 has placed an immense strain on the healthcare system, resulting in a severe shortage of medical personnel and resources. In addition, the inadequacies of current screening and triage methods, as well as the deficiencies in public health monitoring systems, have created significant challenges for the public health sector [2]. Artificial Intelligence (AI) technology has the potential to address some of the deficiencies in the public health system, providing partial compensation for the shortcomings. AI-based tools can help to improve the accuracy and efficiency of screening and triage processes, as well as enhance disease surveillance and monitoring capabilities. AI can also aid in the development of predictive models for disease outbreaks, enabling healthcare organizations to take proactive measures to prevent or mitigate the spread of infectious diseases. Overall, the use of AI in the healthcare sector has the potential to improve patient outcomes, optimize resource allocation, and enhance the overall effectiveness of public health systems [3]. To help clinicians make quick and precise decisions in illness analysis, picture analysis, patient categorization, and disease prediction, it may make full use of its qualities and integrate with other already used medical tools [4-6]. It is imperative to address the dearth of medical resources, bolster the precision of diagnoses, diminish the incidence of human error, and augment the capacity for diagnosis and treatment in underprivileged regions [4]. To curb the dissemination of COVID-19, this manuscript carries out a comprehensive evaluation of the studies on AI technology, taking into account the following four domains: outbreak patterns, aided diagnosis of afflicted patients, aided treatment of COVID-19 patients, and anticipation of malady states and patient prognosis.

LITERATURE REVIEW

AI technology facilitates the diagnosis of COVID-19 patients

According to China's COVID-19 diagnosis and treatment protocol's (Trial Version 9) novel Coronavirus infection criteria: The primary criteria for diagnosis is a positive Reverse Transcriptase-Polymerase Chain Reaction (RT-PCR) of novel Coronavirus based on a thorough examination of the epidemiological history, clinical signs, and laboratory testing [7]. Without testing supplies and trained inspectors, nations worldwide cannot identify and treat potentially infected people promptly, which contributes to the spread of the epidemic. Several experts have proposed employing AI to model and evaluate the data of diverse specimens that may discriminate between novel coronavirus infection and non-coronavirus illness to reduce the load on medical resources.

Image diagnostics supported by AI

Performing X-ray examinations and CT scans on patients with COVID-19 infection is one of the fundamental approaches to diagnose the disease. However, due to a scarcity of radiologists, the exponential growth of COVID-19 cases, and the varying levels of expertise in imaging diagnosis among radiologists, the burden on physicians is increasing and diagnostic accuracy can be inconsistent [8-10]. Research conducted by Qiao F, et al. demonstrates that utilizing an AI-assisted imaging diagnostic system can expedite screening for positive patients (0.19

seconds/lesion with the auxiliary system, 98% accuracy; 2.0 seconds/lesion, 90% accuracy) [11]. Ying Weifeng, et al. studied the comparison of the diagnostic efficacy of AI and radiologists with different levels of experience in diagnosing COVID-19 using CT scans [12]. These two studies demonstrate that AI-assisted imaging diagnosis can compensate for the lack of experience among low-experience radiologists and accurately diagnose COVID-19. Currently, most studies use Convolutional Neural Networks (CNN) to extract features from lung images of COVID-19 patients and non-infected individuals as the imaging data basis for building AI models. The data is divided into training sets to fit various classic algorithms, and the trained models are evaluated using the test sets to determine the final performance of the model [13-15]. The data is divided into training and test sets to fit various classical algorithms, and the trained model is evaluated using the test sets to determine the final performance of the model [16,17]. Blaha, et al. established a theoretical framework for future model applications in practice by training multiple models using image data and comparing the classification performance of these models to select the best model [18]. The findings from various studies suggest that AI technologies can assist clinicians in assessing the imaging data of COVID-19 patients quickly and accurately to a certain extent. This can potentially improve the speed and accuracy of diagnosis, leading to better patient outcomes.

The utilization of AI technology in analyzing blood samples aid in the diagnosis of patients with COVID-19

Certain underdeveloped nations and regions require access to CT, CXR, and ultrasound technology for diagnosing COVID-19, but are limited to basic blood testing facilities due to the need for widespread screening in certain areas of the epidemic and the high cost of imaging equipment [19-21]. To complement traditional diagnostic methods, researchers have developed blood sample-based screening techniques for identifying individuals who have contracted COVID-19. These innovative methods involve analyzing clinical blood samples and have shown promising results in detecting the presence of the virus. This innovative approach involves analyzing clinical blood samples and was introduced by Brinati D, et al. improved the machine learning model to differentiate between new coronavirus-positive and negative patients by using data from a single blood sample [19]. Samin BR, et.al. constructed machine learning and deep learning models to differentiate COVID-19 infected individuals from three traditional blood test data sets with varied features due to the unreliability of model implementation [21]. In the three data sets, there were 177, 786, and 80 patients with COVID-19 positivity, while there were 102, 838, and 520 patients with COVID-19 negativity. Each data set contained information on 15, 34, and 19 patient characteristics. The initial data collection, for instance, had inflammatory agents and other markers. The results show that the Deep Neural Network (DNN) is the best model for training and testing under four times cross-validation. Blood testing is a valuable tool for identifying infected individuals, complementing RT-PCR and CT scans by offering quick preliminary tests and assisting with other diagnostic techniques. AI technologies can hasten blood tests to help diagnose novel Coronavirus pneumonia, hastening to screen, prevent transmission, and reduce resource waste.

AI aided in screening COVID-19 patients using breath sounds and cough waveforms

Pulmonary disorders can result in glottal closure dysfunction, restricted or obstructed airways, which could potentially impact changes in vocalization, such as coughing, breathing, and speech. Consequently, researchers have sought to rapidly screen for the risk of contracting COVID-19 by analyzing the dissimilarities in vocal patterns between infected patients and healthy individuals [22,23]. Pahar M, et al. utilized smartphones to gather two cough audio datasets (Coswara and Sarcos) from volunteers across six continents [22]. These recordings were segmented into individual fragments and subjected to a feature extraction pre-processing phase. The researchers then employed seven machine learning classifiers to learn from and evaluate the two datasets, ultimately achieving the ability to distinguish between COVID-19 coughs and healthy coughs. Pahar M, et al. employed audio data containing coughs, sneezes, speech, and other noise, excluding data from COVID-19 positive patients, to pre-train three deep neural networks: CNN, LSTM, and RESNET50. They then utilized bottleneck features to extract features from cough audio of COVID-19 positive patients and performed transfer learning on the three models [24]. The results revealed that the RESNET50 classifier provided the best or near-best performance on all datasets, with AUC values of 0.98, 0.94, and 0.92 for all three sound categories (coughing, breathing, and speaking), respectively. As the data can be obtained from smartphones, and the model can be installed on such devices, the cough classification model can be applied to enable patients to use their own symptoms to determine whether to seek medical attention while staying at home. Zhu H, et al. utilized 3M Littmann stethoscopes with recording and transmission capabilities to conduct lung auscultations on 172 COVID-19 patients (classified as mild, severe, or critical) and 45 healthy individuals at 6-10 lung sites per patient [25]. The recorded data was transmitted to a computer to construct the dataset, which was then employed to classify lung auscultations using a CNN. The results showed the model exhibited excellent performance, with an AUC of 0.9999, sensitivity of 0.9938, and specificity of 0.9979. This study model can accurately and efficiently distinguish COVID-19 patients with varying degrees of severity, providing an auxiliary diagnostic tool for assessing patient conditions and laying the foundation for the clinical application of AI auscultation systems.

AI-decided additional indicators in COVID-19 patient screening

Convolutional Neural Network models applied to Electrocardiograms (ECGs) can detect subtle subclinical patterns in the ECG to determine whether there are hidden or impending cardiovascular diseases, including left ventricular dysfunction, intermittent atrial fibrillation, and others [26,27]. Attia ZI, et al. investigated the use of AI techniques to screen ECG in COVID-19 positive patients, training Convolutional Neural Networks using 26153 ECG (33.2% novel Coronavirus positive), 3826 ECG (33.3% novel Coronavirus positive), and 7870 ECG (32.7% novel Coronavirus positive) [28]. The results showed that AUC (0.780), specificity (12.1%), and negative predictive value (99.2%) of AI-assisted ECG could be. Its negative predictive value was more significant (99.2%). This could aid in creating ECG-based methods for quick population screening in pandemic containment. With the emergence of new variants of the coronavirus, the sensitivity of PCR testing may decrease, thereby lowering the specificity of reagents for virus detection. As a result, some scholars are striving to achieve a minimal sample size and reagent-free method for COVID-19 nucleic acid testing [29,30]. Ember K, et al. proposed a workflow for detecting changes in molecular spectra related to saliva in COVID-19 patients by collecting and preparing dried saliva droplets [29]. Using saliva samples from 37 COVID-19 patients and 513 negative patients obtained according to collection standards, molecular spectra data were recorded by Raman spectrometry and classified using a machine learning method (support vector machine). The results showed an AUC of 0.8, sensitivity of 79% and specificity of 75%. The combination of Raman spectrometry and AI for virus screening has higher sensitivity and can complement existing diagnostic methods. The use of different detection methods can alleviate the pressure of sudden increases in patient visits and provide more comprehensive diagnosis of patients by compensating for the shortcomings of different detection methods.

COVID-19 PATIENT TREATMENT WITH AI ASSISTANCE

AI for screening and recommending drugs for the treatment of COVID-19

The COVID-19 outbreak initially presented with symptoms identical to those of the SARS virus, and as a result, treatment protocols for SARS were primarily utilized. Traditional Chinese medicine has been employed in the treatment of COVID-19 due to its success in treating SARS and its superior efficacy in treating the disease [31].

Zheng W, et al. utilized an ontological side effect framework based on officially recommended prescriptions from traditional Chinese medicine hospitals to categorize the components of traditional Chinese medicine into different attributes, such as medicinal properties of warm, cool, cold, hot, and equal [32]. This was done to evaluate the impact of traditional Chinese medicine on the treatment of COVID-19. An Artificial Neural Network (ANN) model was trained on prescriptions with various properties and labels (safe or dangerous), and a safety index was generated. The study found that traditional Chinese medicine prescriptions with a Safety Index (SI)>0.8 are advised to be filled, while prescriptions with a SI of 0.2 are deemed risky and should not be filled. Instead, if another prescription is appropriate, it should be considered. To broaden the potential treatment of COVID-19 and provide more options for treating patients, the authors also applied the model to other well-known TCM prescriptions that were not included in the recommended list but were traditionally used for the treatment of rheological diseases. AI technology in traditional Chinese medicine offers reasonable recommendations for the selection of TCM medications and provides a theoretical framework for treating different diseases in the future, allowing for the development of a more reasonable recommendation list of TCM prescriptions [33]. Western medications have also been utilized to treat COVID-19, alongside traditional Chinese medicine. During the early stages of the pandemic, certain medications were unavailable, leading clinical studies to focus on already available medications [34]. In the search for new treatments, numerous researchers have examined hundreds of potential novel Coronavirus medication candidates [35]. Due to the incomplete verification of the efficacy of many drugs, Riva L, et al. collected 3635 drugs related to the treatment of COVID-19 using CTD base [34]. They constructed a COVID-19 knowledge graph based on the interactions between virus envelopes, host genes, drugs, and epitopes. Subsequently, they applied a deep graph neural network method based on biological interactions to deduce the therapeutic effects of candidate drugs. Based on clinical trial history, they prioritized candidate drugs and then verified them through their gene maps, *in vitro* experimental efficacy, and population-based therapeutic effects. Ultimately, they identified drugs that could be repurposed for the treatment of COVID-19. Prior to the availability of specific drugs for the treatment of COVID-19, these screened drugs can address the current shortage of medications for the treatment of COVID-19.

The application of AI techniques in intubation treatment for COVID-19 patients

According to the Diagnosis and Treatment Protocol for Novel Coronavirus Pneumonia (Trial Version 9), COVID-19 patients should receive corresponding oxygen therapy measures based on their different conditions. For severe and critically ill patients whose conditions do not improve, endotracheal intubation and mechanical ventilation are necessary [7]. Salah B, et al. used two physiological respiratory signals of COVID-19 patients diagnosed in hospitals to predict the intubation rate every hour and analyze whether severe and critical COVID-19 patients were intubated [36]. They also created an S24 severity score to measure the severity of the patient during the preceding 24 hours. Based on the varied intubation rates and S24 scores produced by the model, patients were divided into three categories, which helped clinical staff in deciding whether to administer intubation therapy. Understanding the risk factors of extubation failure can also assist clinical doctors in determining the ideal time point for removing the artificial ventilation tube, in order to minimize the intubation rate for patients with a greater need to remove the tube. Leuren LM et al. incorporated risk factors for extubation failure into machine learning models (logistic regression, decision trees, and XG Boost algorithms) to assist clinical doctors in determining the optimal time for extubation in COVID-19 patients [37]. They used the SHAP framework to estimate the importance of predictive factors in the model. Among a large number of clinically important predictive factors, ventilation characteristics, inflammatory markers, mental status, and BMI were identified as the most important predictive factors for extubation failure. The study's conclusion suggests that these important predictive factors should be considered when determining the readiness for extubation to avoid adverse outcomes in patients after extubation.

The implementation of AI in forecasting the medical condition and prognosis of COVID-19 patients

The employment of AI technology has been widely utilized in COVID-19 research to resolve epidemiological and clinical predicaments, encompassing the timely detection of disease outbreaks, the scrutiny of jeopardy factors, and the anticipation of definitive clinical consequences. Numerous researchers have employed diverse predictive indicators in their investigation of COVID-19 to evaluate the prognosis of the disease's ultimate clinical outcome. These predictive indicators comprise blood samples, electrocardiograms, imaging data (CT, XCR), respiratory parameters, clinical symptoms, and other relevant information [38-45]. The concluding indicators of the study were also varied, with a primary focus on the severity of the illness, the risk of mortality, the actual mortality rate, the length of hospitalization, and other relevant factors. For instance, in the research conducted by Sridhar, et al. two deep learning models were established utilizing machine learning algorithms to forecast patient mortality and the likelihood of patients developing cardiovascular disorders [40]. These predictions were based on the ECG data of patients who were infected with the novel coronavirus. The findings of the study indicated that using solely the ECG data from individuals infected with the novel coronavirus was inadequate for modeling purposes. To develop an effective machine learning model, the authors of this research recommend incorporating ECG data from healthy individuals alongside the ECG data from those infected with the novel coronavirus. In another study conducted by Campbell TW, et al. clinical data was utilized to predict unfavorable outcomes, such as ICU admission, ARDS, or endotracheal intubation [45]. The AI-based model developed in this study can rapidly evaluate the severity of the illness and predict the likely course of future developments. This model can aid medical staff in the optimal allocation of hospital resources by prioritizing the care of the most urgent patients.

AI predict the trend of the COVID-19 epidemic outbreak

The COVID-19 pandemic has become a global phenomenon, and numerous studies have been conducted to gain a better understanding of the outbreak's trajectory. Statistical techniques and mathematical models have been used to predict the trend and mortality rates of the epidemic both globally and in specific regions [46]. Recent studies have shown that AI approaches can be useful in predicting specific pandemic patterns, risks, and outcomes. Long Short-Term Memory (LSTM) models, which are deep learning algorithms in AI techniques, can be employed to predict epidemic situations. Given that the trend of the novel coronavirus is constantly changing, many studies have utilized various types of LSTM models to forecast the viruses spread [47-50]. One example is the study by Ruifang MA, et al. which compared the effectiveness of LSTM models and LSTM combined with Markov models for predicting the epidemic trend in various countries and regions [47]. The results showed that the LSTM-Markov model was able to accurately predict the confirmed cases. These prediction results can be used as a reference for government decision-making to formulate appropriate measures with practical significance. Other studies have utilized machine learning models that take inputs based on WHO's daily announcement of new COVID-19 infections, along with variables such as infrastructure, environment, policy, and the infection itself, to predict early signs of containment of the virus in a country. Logistic regression has been used to determine the independent variables that have a significant impact on controlling transmission, as well as their relative importance in the model [51, 52]. Epidemiological studies are an essential tool in preventing the spread of novel coronaviruses and breaking the chain of transmission quickly. Zhang YH, et al. utilized the advanced learning capabilities of AI technology to teach it the essential components of the extracted epidemic transmission [53]. This resulted in the creation of transmission chains, relationship networks, and timelines that were then visualized to provide information for swift and accurate identification of the new Coronavirus transmission chain. This allowed for the prompt tracking of close contacts, leading to effective control of the spread of the disease. These models were also used to evaluate the evolution of the epidemic, related management strategies, and emergency treatment measures, ultimately contributing to the goal of controlling the new Coronavirus outbreak.

DISCUSSION

AI technologies have greatly aided in the detection, screening, prognosis, and classification of COVID-19 cases. However, the current state of AI technology mainly focuses on additional diagnostics, disease outcome prediction, genomics, drug development, and transmission prediction. Despite the numerous applications suggested to predict and diagnose COVID-19, only a small portion of these can operate in real-world scenarios due to the lack of a significant amount of high-quality historical data to train AI models. This is a current limitation in relevant research. Nonetheless, ongoing efforts to collect more data and improve the quality of existing data will facilitate the development of more accurate and reliable AI models for COVID-19 prediction and diagnosis [54]. One limitation with using AI to combat COVID-19 is that practical considerations such as realistic isolation, travel limitations, and immunizations are not always taken into account for transmission prediction. Future research may need to focus on extending predictive models to include these realistic factors. Using clinical data for early COVID-19 diagnosis and symptom prediction is also a challenge, as labeling training samples requires qualified medical staff and takes time. One possible area for future research is the use of unsupervised learning methods to investigate dataset properties and enable automatic categorization. Despite these limitations, using AI technology to limit the spread of COVID-19 can be helpful and save money on medical care [55]. While AI has been used to combat the COVID-19 pandemic, there is still much work to be done to advance these technologies for detection, monitoring, and control, as well as diagnosis and prediction. Future efforts should focus on enhancing existing technologies and gathering more high-quality data to ensure that the created AI models have higher generalization capabilities and are suitable for real-world application scenarios. This includes addressing the practical considerations of COVID-19 control, such as realistic isolation, travel limitations, and immunizations, and improving the accuracy and efficiency of early diagnosis and symptom prediction. As the pandemic continues to evolve, the role of AI in managing and mitigating its impact will undoubtedly become even more critical [56].

CONCLUSION

This study highlights the importance of AI technology in limiting the spread of novel Coronavirus epidemics and provides an overview of research developments in using AI for novel coronavirus pneumonia. However, many studies have focused solely on analyzing existing clinical data and have not externally validated the models built or assessed their practical application. Future applications of these models will require additional external data to assess their actual clinical utility. Despite these limitations, AI technologies can assist in diagnosis, surveillance, treatment discovery, and public health decision-making, which can increase efficiency in the fight against pandemics. As such, continued research and development of AI technologies for pandemic control and management are critical. However, AI-based COVID-19 models can encounter some difficulties during development, including data availability and heterogeneity, insufficient clinical data sharing, difficulties with the security and interpretability of the models, and many others.

Several nations are taking various precautions to halt the pandemic, particularly in Europe and the United States, which implement herd immunization policies and completely liberalize the management of newly infected individuals. In the context of economic globalization, the pressure of future epidemic prevention and control still exists. The form of external prevention and importation of the epidemic in China is severe. The domestic epidemic has yet to be put entirely out. The local epidemic is sporadic, and the emergence of mutated strains of the Neoplasia virus. However, it is anticipated that as AI technology advances and is gradually integrated into actual clinical practice, it will become increasingly significant on the front lines of novel Coronavirus prevention and control.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

1. Böger B, et al. Systematic review with meta-analysis of the accuracy of diagnostic tests for COVID-19. Am J Infect Control. 2021;49:21-29.
2. Lan L, et al. Artificial Intelligence-based approaches for COVID-19 patient management. Intell Med. 2022;1:10-15.
3. Payedimarri AB, et al. Prediction models for public health containment measures on covid-19 using Artificial Intelligence and machine learning: A systematic review. Int J Environ Res Public Health. 2021;18:340-352.
4. Xiaoqiong C, et al. Advances in research on Artificial Intelligence technology in COVID-19. Chinese J Med Phys. 2021;38:915-920.
5. Greenspan H, et al. Position paper on COVID-19 imaging and AI: From the clinical needs and technological challenges to initial AI solutions at the lab and national level towards a new era for AI in healthcare. Med Image Anal. 2020;66:101800.
6. Ghose A, et al. The emerging role of Artificial Intelligence in the fight against COVID-19. Eur Urol. 2020;78:775-776.
7. Notice on the issuance of COVID-19 diagnosis and treatment protocol (Trial Version 9). 2022.
8. Shi F, et al. Review of Artificial Intelligence techniques in imaging data acquisition, segmentation, and diagnosis for COVID-19. IEEE Rev Biomed Eng. 2021;14:4-15.
9. Murphy K, et al. COVID-19 on chest radiographs: A multireader evaluation of an artificial intelligence system. Radiology. 2020;296:E166-e72.
10. Bai HX, et al. Performance of radiologists in differentiating COVID-19 from Non-COVID-19 viral pneumonia at chest CT. Radiology. 2020;296:e46-e54.
11. QIAO F, et al. Design and implementation of a primary screening system for covid-19 patients based on Artificial Intelligence and 5G network. Smart Healthcare. 2021;7:1-3.
12. Wei-feng Y, et al. Comparison of the diagnostic performance in COVID-19 pneumonia between AI and radiologist based on CT images. Radiol Practice. 2020;35:1231-1234.
13. Mahin M, et al. Classification of COVID-19 and pneumonia using deep transfer learning. J Healthc Eng. 2021:3514821.
14. Syed HH, et al. A rapid Artificial Intelligence-based computer-aided diagnosis system for COVID-19 classification from CT Images. Behav Neurol. 2021:2560388.
15. Kogilavani SV, et al. COVID-19 detection based on lung CT scan using deep learning techniques. Comput Math Methods Med. 2022;2022:7672196.

16. Agarwal M, et al. A novel block imaging technique using nine Artificial Intelligence models for COVID-19 disease classification, characterization and severity measurement in lung computed tomography scans on an italian cohort. J Med Syst. 2021;45:28.
17. Qaid TS, et al. Hybrid deep-learning and machine-learning models for predicting COVID-19. Comput Intell Neurosci. 2021:2021;9996737.
18. Balaha HM, et al. Hybrid COVID-19 segmentation and recognition framework (HMB-HCF) using deep learning and genetic algorithms. Artif Intell Med. 2021;119:102156.
19. Brinati D, et al. Detection of COVID-19 infection from routine blood exams with machine learning: A feasibility study. J Med Syst. 2020:44:135.
20. Kukar M, et al. COVID-19 diagnosis by routine blood tests using machine learning. Sci Rep. 2021;11: 10738.
21. Babaei Rikan S, et al. COVID-19 diagnosis from routine blood tests using Artificial Intelligence techniques. Biomed Signal Process Control. 2021:103263.
22. Pahar M, et al. COVID-19 cough classification using machine learning and global smartphone recordings. Comput Biol Med. 2021;135:104572.
23. Alkhodari M, et al. Detection of COVID-19 in smartphone-based breathing recordings: A pre-screening deep learning tool. PLoS One. 2022;17:e0262448.
24. Pahar M, et al. COVID-19 detection in cough, breath and speech using deep transfer learning and bottleneck features. Comput Biol Med. 2022;141:105153.
25. Zhu H, et al. Automatic pulmonary auscultation grading diagnosis of Coronavirus disease 2019 in China with Artificial Intelligence algorithms: A cohort study. Comput Methods Programs Biomed. 2022;213:106500.
26. Attia ZI, et al. An Artificial Intelligence-enabled ECG algorithm for the identification of patients with atrial fibrillation during sinus rhythm: a retrospective analysis of outcome prediction. Lancet. 2019;394:861-867.
27. Attia ZI, et al. Screening for cardiac contractile dysfunction using an Artificial Intelligence-enabled electrocardiogram. Nat Med. 2019;25:70-74.
28. Attia ZI, et al. Rapid exclusion of COVID infection with the Artificial Intelligence electrocardiogram. Mayo Clin Proc. 2021;96:2081-2094.
29. Ember K, et al. Saliva-based detection of COVID-19 infection in a real-world setting using reagent-free Raman spectroscopy and machine learning. J Biomed Opt. 2022;27.
30. Zhou M, et al. Update on COVID-19 in 2021. Front Med. 2022;45:67-71.
31. Yuanye Z, et al. Research progress on chemical composition and clinical efficacy of LianhuaQingwen (LHQW) capsule, a Traditional Chinese Medicine (TCM) used to treat COVID-19. J Pharm Pract Res. 2021;39:291-294.
32. Wang Z, et al. Evaluating the Traditional Chinese Medicine (TCM) officially recommended in china for COVID-19 using Ontology-based Side-Effect Prediction Framework (OSPF) and deep learning. J Ethnopharmacol. 2021;272:113957.
33. Lu L, et al. Construction of a data mining platform for medical cases of famous Chinese medicine doctors based on python. Modernization of Traditional Chinese Medicine and Materia Medica-World Science and Technology. 2021.

34. Riva L, et al. Discovery of SARS-CoV-2 antiviral drugs through large-scale compound repurposing. Nature. 2020;586:113-119.
35. Brimacombe KR, et al. An opendata portal to share COVID-19 drug repurposing data in real time. BioRxiv. 2020;5:135046.
36. Boussen S, et al. Triage and monitoring of COVID-19 patients in intensive care using unsupervised machine learning. Comput Biol Med. 2022;142:105192.
37. Fleuren LM, et al. Predictors for extubation failure in COVID-19 patients using a machine learning approach. Crit Care. 2021;25:448.
38. Zhang RK, et al. Using different machine learning models to classify patients into mild and severe cases of COVID-19 based on multivariate blood testing. J Med Virol. 2022;94:357-365.
39. Altini N, et al. Predictive machine learning models and survival analysis for COVID-19 prognosis based on hematochemical parameters. Sensors. 2021;21:8504.
40. Sridhar AR, et al. Identifying risk of adverse outcomes in COVID-19 patients *via* Artificial Intelligence-powered analysis of 12-lead intake Electrocardiogram. Cardiovasc Digit Health J. 2021;3:62-74.
41. Ortiz A, et al. Effective deep learning approaches for predicting COVID-19 outcomes from chest computed tomography volumes. Sci Rep. 2022;12:1716.
42. Hipolito Canario DA, et al. Using Artificial Intelligence to risk stratify COVID-19 patients based on chest X-ray findings. Intell Based Med. 2022;6:100049.
43. Annapragada AV, et al. SWIFT: A deep learning approach to prediction of hypoxemic events in critically-Ill patients using SpO2 waveform prediction. PLoS Comput Biol. 2021;17:e1009712.
44. Lyu Z, et al. Value of CT findings in predicting transformation of clinical types of COVID-19. J Cap Med Univ. 2020;41:340-344.
45. Campbell TW, et al. Predicting prognosis in COVID-19 patients using machine learning and readily available clinical data. Int J Med Inform. 2021;155:104594.
46. Saba T, et al. Machine learning techniques to detect and forecast the daily total COVID-19 infected and deaths cases under different lockdown types. Microsc Res Tech. 2021;84:1462-1474.
47. Ma R, et al. The prediction and analysis of COVID-19 epidemic trend by combining LSTM and Markov method. Sci Rep. 2021;11:17421.
48. Alkhammash EH, et al. Novel prediction model for COVID-19 in Saudi Arabia based on an lstm algorithm. Comput Intell Neurosci. 2021;2021:6089677.
49. Chandra R, et al. Deep learning *via* LSTM models for COVID-19 infection forecasting in India. PLoS One. 2022;17:e0262708.
50. Kumar RL, et al. Recurrent neural network and reinforcement learning model for COVID-19 prediction. Front Public Health. 2021;9:744100.
51. Kasilingam D, et al. Exploring the growth of COVID-19 cases using exponential modelling across 42 countries and predicting signs of early containment using machine learning. Transbound Emerg Dis. 2021;68:1001-1018.
52. Malki Z, et al. The COVID-19 pandemic: prediction study based on machine learning models. Environ Sci Pollut Res Int. 2021;28:40496-40506.
53. Zhang YH, et al. Application of Artificial Intelligence in prevention and control of COVID-19 in Guangzhou city. Europe PMC. 2020;54:1465-1468.

54. Comito C, et al. Artificial Intelligence for forecasting and diagnosing COVID-19 pandemic: A focused review. Artif Intell Med. 2022;128:102286.
55. Aggarwal P, et al. COVID-19 image classification using deep learning: Advances, challenges and opportunities. Comput Biol Med. 2022;144:105350.
56. Naudé W. Artificial Intelligence *vs* COVID-19: limitations, constraints and pitfalls. AI & society. 2020; 35:761-765.