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# COVID-19 and Radiology: Lessons Learned and Future Directions

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**Abstract**

**Background:** The COVID-19 pandemic, caused by the SARS-CoV-2 virus, has significantly impacted global health, necessitating rapid advancements in diagnostic methods. Radiology, particularly through the use of Artificial Intelligence (AI), has emerged as a critical tool in the early detection and management of COVID-19.

**Methods:** This review examines the application of AI-driven machine learning (ML) and deep learning (DL) techniques in the analysis of medical imaging, specifically chest X-rays and computed tomography (CT) scans, to diagnose COVID-19. We assessed various studies that implemented these technologies, focusing on their methodologies, accuracy, and diagnostic capabilities.

**Results:** The findings indicate that AI algorithms can analyze imaging data with remarkable speed and accuracy, achieving sensitivity rates comparable to experienced radiologists. For instance, deep learning models demonstrated accuracy levels exceeding 90% in identifying COVID-19 pneumonia from CT scans. Additionally, AI has facilitated the development of predictive models for disease severity, aiding clinical decision-making during the pandemic.

**Conclusion:** The integration of AI in radiological practices has proven to be a game-changer in the fight against COVID-19, enhancing diagnostic efficiency and accuracy. However, challenges such as data quality, algorithm interpretability, and the need for standardized protocols remain. Future research should focus on refining these technologies and ensuring their clinical applicability to better prepare for potential future health crises.

**Keywords:** COVID-19, radiology, artificial intelligence, machine learning, deep learning.

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## 1. Introduction

Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) is now a significant global viral illness. The coronavirus 2019 (COVID-19), caused by the SARS-CoV-2 virus, was first identified in Wuhan, China, in December 2019 and subsequently spread globally. On 3 January 2020, the World Health Organization declared COVID-19 a Public Health Emergency of International Concern (PHEIC) and confirmed it as an epidemic on 11 March 2020. This illness has been reported in 216 countries and areas since May 16, 2020. The illness has proliferated, resulting in significant repercussions, with 86,159,886 confirmed cases of coronavirus and 1,861,764 fatalities as of January 5, 2021 [1].

The healthcare sector is actively seeking innovative tools and methodologies to monitor and manage the proliferation of the coronavirus outbreak during this global health disaster. One of the most significant applications of global technology now is Artificial Intelligence (AI), which can monitor the transmission rate and assess the growth rate of the coronavirus, as well as evaluate the danger and severity of coronavirus patients. AI can predict the likelihood of mortality by effectively analyzing historical patient data. Artificial intelligence may aid in combating the virus via individual testing, medical support, data analysis, and suggestions for illness management [2,3].

To address intricate issues in our lives, AI encompasses a wide range of subfields. The sub-areas include learning, preparation, cognition, information representation, and information retrieval. Machine Learning (ML) and Deep Learning (DL) are subfields of Artificial Intelligence (AI) including various methods that provide intelligent models for task identification or clustering.

Machine Learning is a subset of Artificial Intelligence that involves the algorithmic modeling of statistical models and requires little expertise to address issues. Logistic Regression (LR), Decision Tree (DT), Random Forest (RF), K-nearest Neighbor (KNN), Adaboost, K-means Clustering (KC), Density Clustering (DC), Hidden Markov Models (HMM), Support Vector Machine (SVM), Naive Bayes (NB), Restricted Boltzmann Machines (RBM), and Artificial Neural Networks (ANN), including Recurrent Neural Networks (RNN), Long Short-Term Memory (LSTM), Autoencoder (AE), and Generative Adversarial Networks (GAN), are machine learning techniques [4,5].

Deep Learning (DL) is a subset of Machine Learning (ML) that focuses on constructing deep neural network models that acquire knowledge from data using feedforward and backpropagation techniques. Following machine learning, deep learning arose and surpassed it in several tasks during the last two decades. Nonetheless, a substantial volume of material is required for comprehension. Notable instances of deep learning, when much data is unnecessary for training, include transfer learning and generative models. Deep Learning methods often include Deep Belief Networks (DBN), Deep Neural Networks (DNN), and Deep Convolutional Neural Networks (Deep CNN) [6-9].

Research in the industrial, medical, technical, and military sectors has successfully used sophisticated AI-based machine learning and deep learning approaches in the fight against COVID-19 shortly after the outbreak, achieving significant progress [10]. In medical image analysis, machine learning and deep learning facilitate COVID-19 diagnosis and provide non-invasive detection methods to protect medical professionals from pathogen exposure, while also providing a severity level for subsequent treatment of the patient. In virology research, machine learning and deep learning are used to analyze the genetic characteristics of SARS-CoV-2 proteins and to forecast innovative combinations for medication development and immunization. Furthermore, using extensive COVID-19 case data and social media data, AI algorithms grounded in machine learning and deep learning develop disease transmission models that precisely forecast outbreaks, transmission pathways, transmission lists, and impacts. Machine learning and deep learning are extensively used in epidemic prevention and public surveillance, including security screenings at airports, patient monitoring, and epidemic identification [11-14].

This assessment delineates the primary emphasis of artificial intelligence, emphasizing machine learning and deep learning in COVID-19 research, including illness diagnostics and the development of drugs and vaccines. Be aware that, owing to the rapid progression of the COVID-19 outbreak, we have referenced several published studies prior to comprehensive evaluation, necessitating a review of their accuracy and quality in peer assessment. Figure 1 presents a taxonomy of our survey on machine learning and deep learning studies pertaining to COVID-19 diagnosis and therapy.

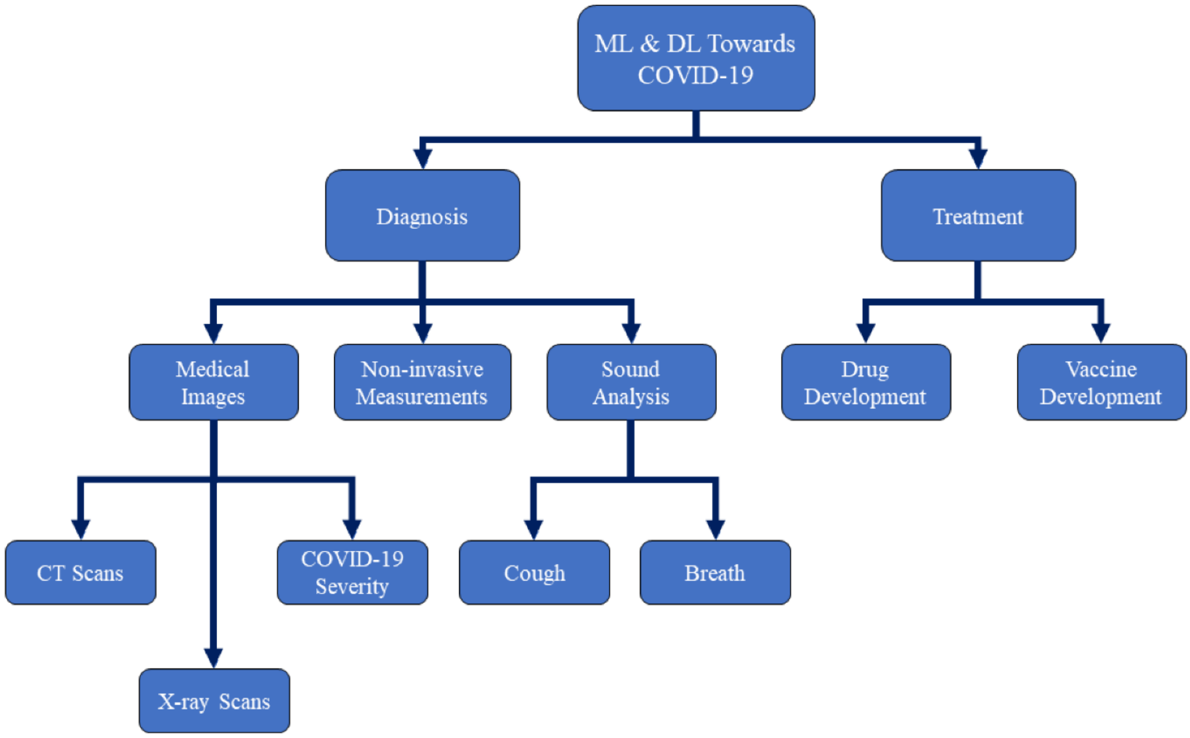


**Figure 1. A classification of our survey on Machine Learning (ML) and Deep Learning (DL) research pertaining to the diagnosis and treatment of Coronavirus 2019 (COVID-19).**

## 2. Utilization of AI-Driven Machine Learning and Deep Learning for COVID-19 Detection in Medical Imaging

The Coronavirus (COVID-19) epidemic is escalating both domestically and globally. In the global struggle against COVID-19, medical imaging, including X-ray and computed tomography (CT), is pivotal, and recent advancements in AI enhance the efficacy of imaging technologies and assist healthcare professionals. Medical imaging research is often used by doctors for the detection of COVID-19 [3]. Chest X-ray and lung CT image samples are predominantly used in clinical imaging studies for COVID-19. Artificial intelligence innovation significantly influences medical imaging diagnostics. It has yielded significant outcomes in picture identification, organ recognition, geographic infection categorization, and illness classification. It not only reduces the diagnostic imaging time for the radiologist but also enhances the accuracy and efficacy of the diagnosis. AI may improve job performance by providing accurate diagnostic accuracy in X-ray and CT imaging, hence simplifying testing. Computer-aided networks enable radiologists in clinical decision-making, namely in the detection, monitoring, and prognosis of illnesses. We will thoroughly examine the advancements of AI methodologies in chest X-ray and CT imaging [15-20].

## 3. Detection of Chest CT Images

A significant aspect of evaluating individuals with suspected SARS-CoV-2 infection is the chest CT image. Research on the use of COVID-19 imaging in therapy and diagnosis is expanding. The infection induces a wide range of CT scan imaging findings, mostly ground-glass opacities and peripheral lung consolidations. The sensitivity of chest CT for diagnosing COVID-19 is markedly elevated and may precede a positive viral laboratory result. Consequently, hospitals with high admission rates use CT scans for the rapid assessment of patients with suspected COVID-19 in epidemic regions, when the primary healthcare system is strained. Chest CT is essential for assessing COVID-19 patients with severe and complex respiratory symptoms. Scans facilitate the assessment of lung compromise and the progression of the individual's illness, aiding in medical decision-making [21].

There is an increasing recognition of the abrupt emergence of lung abnormalities induced by COVID-19 in CT scans performed for various clinical purposes, including abdominal scans for gastrointestinal disorders or in patients presenting without respiratory symptoms. During this epidemic, alleviating the burden on physicians may render the assessment of AI the most crucial element. While human interpretation of a CT scan may take up to 15 minutes, artificial intelligence can analyze the pictures in 10 seconds [3]. Consequently, sophisticated image processing using artificial neural networks has the potential to markedly enhance the efficacy of CT in COVID-19 identification, enabling a substantial number of patients to be diagnosed swiftly and accurately. The progression of AI-driven CT imaging assessments typically includes the following stages: delineation of the Region of Interest (ROI), excision of pulmonary tissue, detection of localized infection, and categorization of COVID-19. A fundamental foundation for analyzing AI-generated imaging is the identification of pulmonary organs and regions of interest (ROIs). ROI has been validated for further testing and analysis in CT imaging of the lungs, lung lobes, bronchopulmonary segments, and areas exhibiting infection or ulceration. Various kinds of deep learning networks, such as U-Net, V-Net, VB-Net, and VNET-IR-RPN, have been used for CT image categorization [22-25].

Out of 905 patients evaluated using real-time RT-PCR and next-generation RT-PCR, 419, or roughly 46.3%, were verified by an AI device to have SARS-CoV-2. The AI approach employs deep convolutional neural networks to analyze the picture features and characteristics of persons infected with SARS-CoV-2 in primary CT scans. Subsequently, based on clinical information, SVM, RF, and MLP classifiers were used to detect SARS-CoV-2 patients [26]. The AI system utilizes radiological data and medical parameters to predict COVID-19 status. The deep CNN-based AI system achieved an AUC of 92% and exhibited equivalent sensitivity to that of the senior thoracic radiologist in the experimental cohort of 279 patients. Moreover, the Artificial Intelligence (AI) method improved the identification of patients seeking RT-PCR confirmation of COVID-19 who provided routine CT scans, accurately classifying 17 out of 25 patients (68%), all of whom were assessed by radiologists as COVID-19 negative [4]. The training dataset included 25 COVID-19-positive patients that were classified as negative by two radiologists following chest CT evaluation. The CNN-based model classified 13 of 25 pictures, almost 52%, as positive for COVID-19. The clinical model identified 16 of 25 photos (64%) as positive for the disease, while the joint model identified 17 of 25 images (68%) as positive. In contrast, the senior radiologist and their fellows assessed none of the images (0%) as positive for disease [4].

Researchers are endeavoring to create various AI resources to swiftly break down photos using deep learning and identify COVID-19 characteristics. A research team, directed by Bo Xu from the Tianjin Medical University Cancer Institute and Hospital, conducted CT scans on 180 patients diagnosed with severe viral pneumonia before the COVID-19 epidemic, alongside 79 patients confirmed to have COVID-19, to develop an AI methodology for classifying COVID-19. They provided random images of patients to train and evaluate a deep CNN-based system. The researchers reported in their results published in medRxiv [6] that their model identified COVID-19 with an accuracy of 89.5% using CT scans. Two radiologists indicated an accuracy of roughly 55% in their analysis of the photographs. The team verifies that the data demonstrate AI can provide an accurate analysis from a CT scan. The RADLogics method [7] successfully identified and facilitated the improvement of COVID-19 patients.

Two investigations, reported in [4,8], support this notion by using deep learning trained on CT scans as a rapid diagnostic tool to detect COVID-19 infection in patients admitted to hospitals requiring medical imaging analysis. In [8], researchers from Macau University of Science and Technology used 532,000 CT scans from 3,777 patients in China to train and evaluate their AI-based models, focusing on the characteristic lesions seen in the lungs of COVID-19 patients. The AI model accurately detected coronavirus-induced pneumonia in at least 85% of cases during a pilot trial with a database of 417 patients across four distinct groups in several Chinese hospitals.

Radiologists seem to have significant challenges in differentiating between COVID-19 and pneumonia indicators on CT scans. VIDA Diagnostics has created a LungPrint device that use AI to analyze CT scans for the precise identification of respiratory illnesses, including indicators of COVID-19. In [10], NIH and NVIDIA researchers endeavored to develop a deep learning system for detecting COVID-19 from chest CT scans, utilizing datasets from four hospitals in China, Italy, and Japan. This study used 2724 samples from 2619 patients, using two models (Full 3D and Hybrid 3D) in succession to develop the final prediction model for COVID-19. Both types are operational. The first model had a fixed input size including the whole 3D lung region. At constant picture resolutions (hybrid 3D), the second model used an average score for many areas inside each lung. The hybrid three-dimensional (3D) model attained a validation accuracy of 92.4% in identifying COVID-19 and other pneumonia, whereas the complete 3D model reached an accuracy of 91.7%.

To extract regions of interest from each CT picture and obtain a training curve for suspected lesions, Chen et al. [11] developed a U-Net++ deep learning architecture. A total of 46,096 anonymous pictures were gathered and analyzed for model development and validation from 106 patients hospitalized, including 51 laboratory patients diagnosed with COVID-19 pneumonia and 55 control patients with other diseases at Renmin Hospital of Wuhan University in China. On 5 February 2020, twenty-seven consecutive patients undergoing CT scans were assembled at Renmin Hospital of Wuhan University to evaluate the efficacy of radiologists relative to the 2019-CoV pneumonia model. The U-Net++ model attained a sensitivity of 100%, specificity of 93.55%, and accuracy of 95.24% using a retrospective dataset. Huang et al. [12] used the AI-driven InferReadTM CT pneumonia technique to precisely evaluate enhancements in the pulmonary load of COVID-19 patients. The tool has three modules: pulmonary and lobe extraction, pneumonia categorization, and quantitative analysis. The CT imaging features of COVID-19 pneumonia are categorized into four classifications: mild, moderate, severe, and critical. A professional deep learning program autonomously assessed the degree of CT lung natural function for the whole lung and its five lobes and conducted a comparative analysis of CT scans throughout follow-up. A total of 126 COVID-19 individuals were evaluated, including six mild, 94 intermediate, 20 severe, and six catastrophic cases. The rate of CT-based natural action varied significantly across the first clinical groups, increasing progressively from moderate to severe (all $p < 1\%$).

Qi et al. [13] acquired 71 CT images from 52 patients with authorized COVID-19 diagnoses across five hospitals. The Pyradiomics technology was used to extract 1218 features from each CT scan. The CT radiomics models focused on LR and RF algorithms. They were developed using extracts from pneumonia lesions during training and interactions. The effectiveness of prediction was assessed at both the lung lobe and patient levels inside the experimental database. The categories of CT Radiomics concentrate on six second-order features. They successfully differentiated between short-term and long-term stays in patients with SARS-CoV-2-related pneumonia, achieving 97% AUC and 92% LR and RF, respectively. The LR model had 100% sensitivity and 89% specificity, while the RF model demonstrated 75% sensitivity and 100% specificity. A short-term hospital stays lasts less than 10 days, while a long-term hospital stay exceeds 10 days.

## 4. Machine Learning and Deep Learning in Pharmaceutical and Vaccine Development

The integration of extensive data with the ability for automated abstract component learning has significantly influenced the effective use of machine learning. Drug discovery and vaccination significantly impacted two critical domains, whereby machine learning facilitated comprehensive property forecasts, behavioral predictions, response predictions, and ligand-protein interactions. Diverse medication development initiatives and vaccines for SARS-CoV-2 and COVID-19 are recommended to concentrate on proteomic and genomic research. A significant addition to intelligent medicine is the use of machine learning and deep learning in the creation of novel pharmaceuticals and vaccines, which plays a crucial role in the fight against COVID-19 [4,27].

Machine learning and deep learning provide two crucial supporting functions: facilitating the distribution of vaccine components via the analysis of viral protein structures and assisting medical professionals in rapidly reviewing a substantial volume of significant research publications. Three primary categories of vaccines exist: traditional vaccines for pathogens, such as influenza or MMR, utilize live attenuated or inactivated infections; subunit vaccines (e.g., pertussis, shingles) incorporate only specific components of the virus, such as proteins; and nucleic acid vaccines introduce viral genetic material into human cells to enhance the immune response. The latest development is the COVID-19 vaccine, which started testing in the United States this week. Artificial intelligence accelerates the development of subunits and nucleic acids [28].

Understanding protein composition is essential for analyzing its function. Researchers may develop medications that function across diverse protein conformations if the condition is recognized. Nonetheless, determining the unique three-dimensional structure of every protein will need some effort. AI systems using deep learning may streamline the assessment of protein structure and its genetic sequence [29].

In January, Google DeepMind launched AlphaFold, a sophisticated algorithm that predicts the three-dimensional structure of proteins based on their genetic sequences. At the outset of March, the system underwent testing for COVID-19. To evaluate the scientific community's comprehension of the virus, DeepMind has released a protein prediction for many untreated proteins associated with SARS-CoV-2, the primary causative agent of COVID-19. Scientists at the University of Texas at Austin and the National Institutes of Health have used a conventional biological technique to create the first 3D atomic map of a spike protein component of a virus that attaches to human cells [30,31]. Other coronaviruses, such as SARS-CoV and MERS-CoV, have engaged in years of collaboration with the team responsible for this significant achievement. One of the forecasts issued by AlphaFold accurately forecasted this spike structure. Computer simulations for constructing 3D atomic models of the SARS-CoV-2 protein, which corresponded closely with findings from the UT Austin board, were also used by [32,33] at the Institute for Protein Design at the University of Washington. They are now advancing their efforts by engineering novel proteins to mitigate the Coronavirus. These proteins are designed to conform to a protein spike that protects healthy cells against viral invasion.

Researchers used artificial intelligence with cloud computing to inhibit the binding of the Spike protein to the ACE2 receptor in human cells and to develop a potential vaccination for COVID-19 [34]. Researchers at Flinders University investigated the COVID-19 virus and then used their findings to develop a vaccine, termed Covax-19. To ascertain the mechanism by which the virus adversely affects human cells, the researchers used computer-generated models of the S protein and its human receptor, angiotensin-converting enzyme 2 (ACE2). They subsequently endeavored to develop a vaccination capable of inhibiting this process. The researchers used cutting-edge AI and sophisticated cloud computing technologies to accelerate vaccine manufacturing [32,34,36].

Herst et al. [37] identified the SARS-CoV-2 protein sequence from GenBank and using the MSA technique to delineate the nucleocapsid phosphoprotein sequence for further peptide sequencing. It also suggests that a peptide vaccine reliant on CD8 + T-cell immunity is suitable and viable for survivors of the EBOV (West African Epidemic 2013–2016). Ong et al. [38] used machine learning and reverse vaccinology to predict and evaluate potential COVID-19 vaccinations. To characterize possible baptismal candidates, they used RV to analyze bioinformatics pathogen genomes. The sequence of SARS-CoV-2 was identified. The identified proteins of several coronavirus strains, including SARS-CoV, MERS-CoV, HCoV-229E, HCoV-OC43, HCoV-NL63, and HCoV-HKU1, were sourced from Uniprot proteomes. They then used Vaxign and Vaxign-ML to analyze and predict the biological signaling functions of the full proteome of coronaviruses.

Subsequently, using structural, vector support, closeness neighbor, random forest, and overgrowth (XGB) methodologies, they developed the Vaxign-ML model within the framework of ML and RV, and assessed the protein level. To ascertain the protegenicity rate of all WSH-CoV-2 proteins derived from Wuhan-Hu-1, obtained from NCBI, the most robust XGB model was used. An effective immunodeficiency vaccination is defined as a protein with a protegenicity point over 90% (F1-point weight >94% in five-fold combined validation). For the phylogenetic analysis, the NSP3 protein was selected, and its immunogenicity was evaluated by predicting MHC-I and MHC-II T cell epitopes, as well as linear B cell epitopes [39,40].

Researchers from the Computer Science and AI Laboratory (CSAIL) at MIT have recently implemented an innovative technique using an improved machine learning-based approach to choose peptides (short amino acid sequences) anticipated to provide substantial vaccine quantities. The "OptiVax" design program facilitates the creation of novel peptide therapeutics, assesses current vaccinations, and enhances the formulation of existing vaccines. Peptides get mechanical learning points in this program due to their capacity to exhibit responses to antibodies, leading to their selection for broader coverage of individuals who may benefit from this vaccination [41].

Rahman et al. [40] used immunoinformatics techniques and comparative approaches to develop a SARS-CoV-2 anti-peptide vaccine including S (spike), E (envelope), and M (membrane) protein epitopes. To forecast B-specific epitopes in S-proteins, they used the Ellipro antibody epitope prediction system. Ellipro employs several machine learning approaches to predict and display a particular protein sequence or B-cell epitope inside a structure. Sarkar et al. [41] investigated the epitope-based vaccine design for COVID-19. They used a Support Vector Machine approach to predict the toxicity of selected epitopes. Prachar et al. [42] used 19 integrated epitope-HLA technologies, including IEDB, ANN, and PSSM algorithms, to predict and validate 174 SARS-CoV-2 epitopes.

## 5. Conclusion

The COVID-19 pandemic has significantly impacted global wellness, and the incidence of disease-related fatalities continues to rise worldwide. While technology has successfully infiltrated our everyday lives, particularly in machine learning and deep learning, artificial intelligence has also aided individuals in the challenging fight against COVID-19. Deep learning is only one viable method to provide effective data-driven solutions to assist mankind in managing COVID-19.

This study examined AI-driven machine learning and deep learning techniques for the diagnosis and treatment of COVID-19. Furthermore, in the battle against COVID-19, we compiled the AI-driven machine learning and deep learning methodologies, together with the relevant datasets, tools, and performance metrics. This review provides a comprehensive examination of current advanced methodology and applications for machine learning (ML) and deep learning (DL) researchers, as well as the broader health community, detailing how ML, DL, and data might enhance the management of COVID-19 and facilitate further research to prevent future outbreaks. Challenges and possible direction were also offered when using machine learning and deep learning.

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**كوفيد-19 والأشعة: الدروس المستفادة والتوجهات المستقبلية**


**المستخلص**

**الخلفية :**أثرت جائحة كوفيد-19، التي تسبب بها فيروسSARS-CoV-2 ، بشكل كبير على الصحة العالمية، مما استلزم تطورات سريعة في أساليب التشخيص. برزت الأشعة، خاصة مع استخدام الذكاء الاصطناعي(AI) ، كأداة حيوية في الكشف المبكر وإدارة كوفيد-19.
**الطرق :**تستعرض هذه المراجعة تطبيق تقنيات التعلم الآلي (ML) والتعلم العميق (DL) المدعومة بالذكاء الاصطناعي في تحليل التصوير الطبي، وخاصة صور الأشعة السينية للصدر والتصوير المقطعي المحوسب (CT) لتشخيص كوفيد-19. قمنا بتقييم دراسات مختلفة تناولت هذه التقنيات، مع التركيز على منهجياتها ودقتها وقدراتها التشخيصية.

**النتائج :**تشير النتائج إلى أن خوارزميات الذكاء الاصطناعي قادرة على تحليل بيانات التصوير بسرعة ودقة مذهلة، محققة نسب حساسية تضاهي تلك التي يحققها أطباء الأشعة ذوو الخبرة. على سبيل المثال، أظهرت نماذج التعلم العميق مستويات دقة تتجاوز 90% في تحديد التهاب الرئة الناتج عن كوفيد-19 من صور التصوير المقطعي. علاوة على ذلك، ساهم الذكاء الاصطناعي في تطوير نماذج تنبؤية لشدة المرض، مما دعم عملية اتخاذ القرار السريري أثناء الجائحة.

**الاستنتاج :**أثبت دمج الذكاء الاصطناعي في الممارسات الإشعاعية أنه يمثل نقطة تحول في مكافحة كوفيد-19، حيث عزز كفاءة ودقة التشخيص. ومع ذلك، لا تزال هناك تحديات تتعلق بجودة البيانات، وقابلية تفسير الخوارزميات، والحاجة إلى بروتوكولات موحدة. ينبغي أن تركز الأبحاث المستقبلية على تحسين هذه التقنيات وضمان قابليتها للتطبيق السريري لتحسين الاستعداد للأزمات الصحية المحتملة في المستقبل.



**لكلمات المفتاحية :**كوفيد-19، الأشعة، الذكاء الاصطناعي، التعلم الآلي، التعلم العميق.