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A systematic literature review of artificial intelligence methods applied to the Human Epidemic (Covid-19)

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ABSTRACT

The COVID-19 pandemic placed unprecedented pressure on healthcare systems worldwide and accelerated the use of artificial intelligence (AI) in areas such as diagnostics, forecasting, treatment, and disease monitoring. To better understand this trend, we carried out a systematic literature review following PRISMA guidelines. Our review covered studies released between December 2019 and January 2024, drawing from major bibliographic databases and preprint servers. For the search, we applied the keywords (“Artificial Intelligence” OR “Machine Learning” OR “Deep Learning”) AND (“COVID-19” OR “Coronavirus” OR “Pandemic”). Out of approximately 110 retrieved records, 57 studies satisfied the predefined inclusion criteria and were evaluated using the CASP framework. The final body of literature was distributed as follows: disease detection and prediction accounted for about 44% (23 studies), drug and vaccine discovery for 25% , remote healthcare and IoT applications for 19% (10 studies), online social network (OSN) analytics for 4%, and general or multi-modal AI frameworks for 8%. Deep learning models applied to chest CT scans, X-rays, and RT-PCR enhancement frequently reported internal diagnostic accuracies above 90%. Meanwhile, natural language processing and embedding-based OSN methods occasionally identified symptomatic trends several days ahead of official case reports. Despite these advances, common challenges persisted, including heterogeneous datasets, insufficient external validation, and ongoing privacy and ethical concerns. Looking forward, we recommend that future research emphasize multimodal integration of clinical and social media data, establish standardized external benchmarks, adopt explainable AI (XAI) methods, and explore privacy-preserving strategies such as federated learning to strengthen generalizability and promote equitable deployment.

Keywords: artificial intelligence; deep learning; medical imaging; forecasting; federated learning; social media analytics; explainable AI.

1. Introduction

COVID-19, caused by the SARS-CoV-2 virus, was first found in December 2019 and quickly spread to many cities and countries around the world (Ma, Wang et al. 2020, Zhou, Yang et al. 2020, Zhou, Liu et al. 2020), SARS-CoV-2 mainly spreads through tiny droplets in the air when people are close to each other (Wiersinga, Rhodes et al. 2020), The infection can lead to mild symptoms like a cold or could become very serious, causing sepsis and shock (Huang, Wang et al. 2020, Wang, Hu et al. 2020, Wiersinga, Rhodes et al. 2020), It can cause very serious and potentially deadly problems for at-risk groups, especially older people with other health issues. As of March 16, 2021, SARS-CoV-2 has impacted over 190 countries. It has caused serious problems, with more than 110 million confirmed cases and 2.5 million deaths reported. The increasing number of COVID-19 cases and deaths is putting a lot of strain on the available healthcare resources. We need good tools to make it easier to diagnose, treat, and monitor COVID-19, and to improve how healthcare systems work (Yassine and Shah 2020).

Most of the people affected by this virus were simply cured (Lancaster and Cotarlan 2021), However, with the growing increase of time, the WHO has announced COVID-19, an epidemic with an increased risk of The COVID-19 pandemic has severely impacted populations worldwide, especially in countries with fragile healthcare systems. The virus poses a significant threat for two main reasons: first, the vaccination process is not always carried out effectively, and second, transmission occurs easily through both direct and indirect contact with infected individuals (Bastani, Mohammadpour et al. 2021, Choudrie, Banerjee et al. 2021). To mitigate this spread, early detection and isolation of patients in the initial stages of infection are crucial for saving lives. One of the widely used diagnostic approaches is Reverse Transcription Polymerase Chain Reaction (RT-PCR). However, RT-PCR testing is often expensive and time-intensive, requiring specialized equipment, materials, and tools. Moreover, due to financial and technical limitations, many countries face shortages of testing kits (Castiglioni, Ippolito et al. 2021).

Recent research highlights that artificial intelligence offers significant potential, as it can enhance scalability, increase processing efficiency, and in some cases, even surpass human performance in specific healthcare applications (Lawson, Hameed et al. 2019).

In recent years, Online Social Networks (OSNs) have emerged as an unexpected yet valuable source of public health intelligence. Platforms like Twitter generate vast, real-time streams of information where people share their symptoms, personal experiences, and concerns. When processed using natural language processing (NLP) techniques and graph-based models, these data streams can uncover early signals of epidemic trends and shifts in public behavior, often appearing before official reports are released (Cheng, Feng et al. 2020, Santosh, Schwartz et al. 2020). Integrating insights from both clinical records and social

media analytics allows AI-driven systems to provide more comprehensive and timely support for epidemic management.

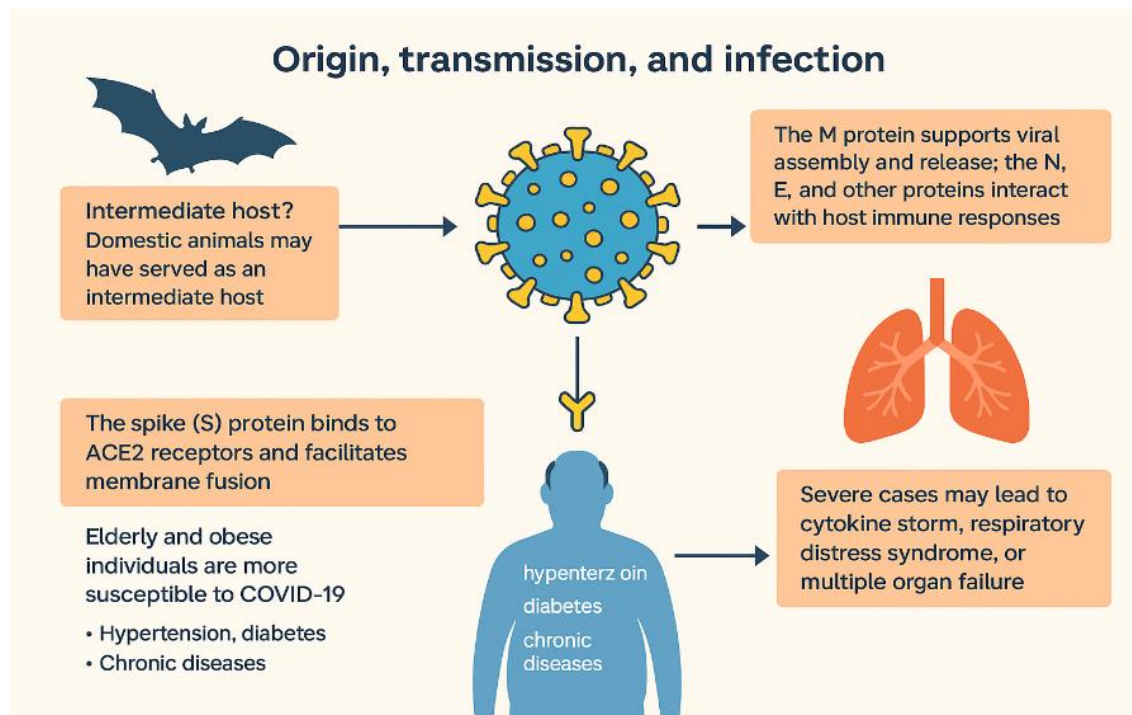


Figure_1. Origin, transmission, and infection of COVID-19 (Li, Dong et al. 2020).

2. Related Work

This section provides a brief overview of studies that have applied artificial intelligence (AI) methods to tackle the human epidemic, specifically COVID-19, (Tayarani 2020). The primary goal of this paper is to conduct a thorough survey of AI applications in addressing the challenges posed by the outbreak. We aim to summarize the various ways AI techniques have been employed, covering research conducted up to the time of writing. The studies are organized to give readers a clear overall perspective. Although detailed, this overview helps in understanding the current role of AI in managing the pandemic. Additionally, we offer insights on potential improvements and suggest directions for future research (Hamed 2020).

This work also seeks to present a comprehensive understanding of COVID-19 and future expectations for controlling the virus's spread. Individuals with pre-existing conditions such as liver disease, diabetes, hypertension, and obesity are particularly vulnerable to infection. Consequently, there is an urgent need

for rapid disease diagnosis, vaccine development, and drug discovery to prevent, detect, and treat this deadly virus. Real-time polymerase chain reaction (RT-PCR) is widely regarded as an accurate and specific tool for diagnosing COVID-19. Globally, around 15 vaccine candidates are being tested, including mRNA-based, DNA-based, nanoparticle, synthetic, and modified virus-like particle vaccines. Several drugs originally approved for other diseases, such as chloroquine, hydroxychloroquine, ivermectin, favipiravir, ribavirin, and remdesivir, have been evaluated for effectiveness against COVID-19. Other approaches, such as convalescent plasma therapy and traditional herbal medicine, have also been explored.

Due to the lack of fully effective treatments or vaccines, preventive measures following WHO guidelines remain the most reliable strategy to combat the pandemic. Governments are encouraged to implement national healthcare programs to minimize exposure risks, particularly for patients with pre-existing medical conditions, in anticipation of future viral outbreaks (Khan, Mehran et al. 2021).

In addition to clinical approaches, recent research has increasingly highlighted the value of Online Social Networks (OSNs) as an early and dynamic source of epidemic signals. Unlike traditional surveillance systems, which often depend on delayed clinical reporting, platforms such as Twitter generate vast streams of real-time, user-generated content. Here, individuals openly share daily health experiences, perceived symptoms, and personal concerns. While informal, these platforms capture lived experiences at scale and offer a unique perspective on the early spread of disease. Artificial intelligence, particularly natural language processing (NLP) and graph-based methods, have been widely applied to OSN data to filter noise, detect health-related patterns, and track behavioral changes. For example,

(Santosh, Schwartz et al. 2020) demonstrated that context-based Twitter embeddings captured early mentions of COVID-19 symptoms, often days before they appeared in official reports. Similarly, (Cheng, Feng et al. 2020) developed an event-detection system that analyzed behavioral shifts across OSNs to detect global health trends and issue timely alerts. These findings suggest that casual online posts such as complaints about loss of smell or persistent cough, can serve as valuable early warning signals for epidemics.

Beyond symptom detection, OSN-based analytics can also uncover patterns of anxiety, misinformation, and public sentiment, which are equally important for crisis management. By combining human-centered insights with clinical data, AI systems can create a more complete model for pandemic surveillance, one that is faster, more flexible, and more in tune with the social realities people face. This kind of integration

doesn’t just improve response strategies; it also helps authorities anticipate new challenges and build public trust through timely, people-focused actions.

Beyond social media networks, broader reviews and technical studies have highlighted the role of AI in healthcare and pandemic management. Evidence shows that AI has been successfully applied in many areas of healthcare, and this review brings together current research on the most advanced applications developed to fight the COVID-19 pandemic.

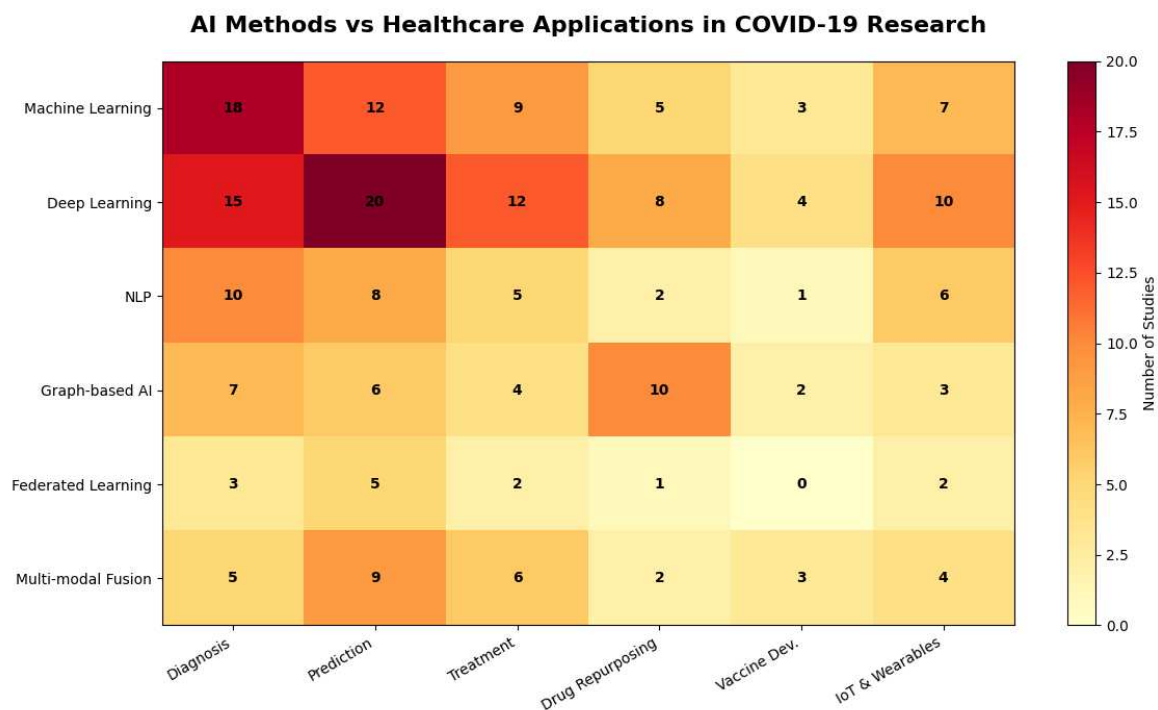


Figure_2. AI methods across healthcare domains during COVID-19, highlighting the most studied combinations.

To illustrate how research priorities have shifted over time, we include a timeline chart showing the annual distribution of studies across key healthcare domains from 2020 to 2024. This visualization highlights the domains that received the most attention in each year and complements the heatmap by adding a temporal perspective to method–domain interactions.

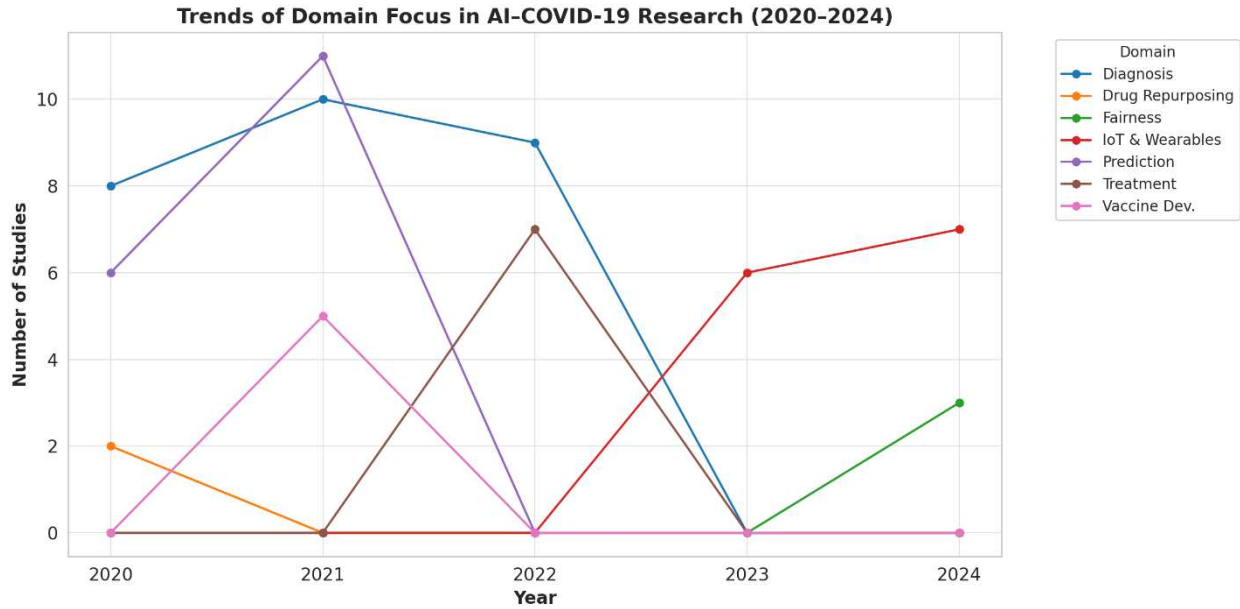


Figure_3. Trends of domain focus in AI–COVID-19 research (2020–2024), yearly evolution of study concentrations.

During the literature review process, relevant studies were collected from databases such as ScienceDirect, Google Scholar, and preprint servers including arXiv, medRxiv, and bioRxiv. This paper critically examines and summarizes recent advancements in AI-based technologies. Key challenges in implementing these technologies are highlighted, and based on updated research and careful analysis, gaps in the current knowledge and future research directions are identified. The study also compares different machine learning (ML) and deep learning (DL) approaches—the most commonly used AI methods—employed for COVID-19 detection, diagnosis, screening, classification, drug repurposing, prediction, and forecasting, providing insights into current research trends. Recent developments in AI have significantly enhanced COVID-19 screening, diagnostics, and prediction, enabling scalable, timely, and reliable solutions, and in some cases, surpassing human performance in certain healthcare tasks. This review aims to offer researchers, healthcare institutions, government agencies, and policymakers valuable insights on how AI can help manage the COVID-19 pandemic and encourage further studies to mitigate its impact (Chang, Zhan et al. 2021). various AI model applications during the COVID-19 pandemic. It evaluates their effectiveness, highlights their strengths and differences, and introduces the primary models along with their characteristics. Literature was retrieved from PubMed, arXiv, medRxiv, and Google Scholar up to February 2020 to identify relevant studies on AI applications in medical contexts for COVID-19. The review categorizes AI applications into six main areas: (i) epidemiology, (ii) diagnosis, (iii) disease progression, (iv) treatment, (v) psychological health impact, and (vi) data security. Continuous advancements in AI have notably enhanced prediction, contact tracing, screening, diagnostics,

treatment, medication, and vaccine development while minimizing human intervention in clinical practice. This study emphasizes the importance of using AI-based supportive tools in managing human diseases. Additionally, it discusses the vital role of clinicians in advancing AI integration. By collaborating, AI experts and healthcare professionals can incorporate AI technologies into existing clinical workflows and information systems. In the future, closer cooperation between AI specialists and medical practitioners is expected to further optimize healthcare solutions (Lalmuanawma, Hussain et al. 2020). The successful use of Machine Learning (ML) and Artificial Intelligence (AI) in previous epidemics has inspired researchers to explore new approaches for combating the novel Coronavirus outbreak. This paper provides a comprehensive review of AI and ML applications in key areas such as screening, prediction, forecasting, contact tracing, and drug development for SARS-CoV-2 and related epidemics. Relevant studies were selected from multiple databases, focusing on the application of AI and ML in addressing COVID-19. A detailed and rapid analysis of abstracts, methodologies, and conclusions was performed to assess the potential of these models in responding to the SARS-CoV-2 pandemic. The paper highlights recent research that employs AI and ML to support scientists in various ways, while also identifying challenges and limitations encountered when applying these algorithms in real-world scenarios. Recommendations are provided for researchers, medical professionals, and policymakers to improve model design and deployment in ongoing and future pandemic responses. Advancements in AI and ML have considerably enhanced processes such as treatment, medication, screening, prediction, forecasting, contact tracing, and vaccine or drug development, reducing the need for direct human intervention in healthcare. Although many models have not yet been fully implemented in practical settings, their current performance shows considerable promise in addressing the SARS-CoV-2 epidemic (Akhbarifar, Javadi et al. 2020). The transfer of large volumes of sensitive patient health data poses significant privacy and security challenges, as individuals may not want their medical information disclosed. To address this issue, this study proposes a remote health monitoring system that incorporates a lightweight block encryption method to secure medical data within a cloud-based IoT environment. In the proposed model, patients' health conditions are monitored by predicting critical events using data mining techniques applied to biological data collected from smart medical IoT devices. The lightweight block encryption ensures that sensitive patient information remains protected. Due to the limited computational resources in IoT platforms, lightweight encryption methods play a vital role in maintaining system efficiency. Experimental results indicate that the K-star classification algorithm outperforms RF, MLP, SVM, and J48 classifiers, achieving an accuracy of 95%, precision of 94.5%, recall of 93.5%, and an F-score of 93.99%. These findings demonstrate that the proposed model provides an effective and secure remote health monitoring solution leveraging IoT data in cloud-based systems (Sheth, Priyal et al. 2024). This study examines the effects of the latest COVID-19 virus on patients using computational

intelligence, including machine learning, artificial intelligence, and IoT-enabled technologies, to manage, analyze, diagnose, and predict COVID-19 outcomes. AI and ML tools offer significant potential in healthcare by enabling early detection, risk assessment, and optimized treatment plans. These technologies can process large datasets to uncover patterns and trends that may be difficult for humans to identify. Moreover, IoT technologies allow healthcare providers to effectively monitor patient conditions and reduce the likelihood of COVID-19 readmissions. Wearable sensors and remote monitoring devices are key examples of IoT-enabled tools essential for tracking virus spread and patient health. These devices collect real-time data on environmental factors, symptoms, and vital signs, providing healthcare professionals with valuable insights into patient health and disease progression. Overall, this study highlights the crucial role of smart technologies in enhancing safety measures, mitigating SARS-CoV-2 exposure, and providing globally relevant insights into the impact of COVID-19 on patients (Ashique, Mishra et al. 2024). Artificial intelligence (AI) has shown its potential to lower the risk of human-to-human transmission of viruses by analyzing, evaluating, and cross-referencing existing data on infection patterns and virus spread. This review highlights the role and importance of modern robotic and automated systems that can support pandemic management. Additionally, it discusses the use of intelligent wearable devices and their potential benefits in monitoring and controlling the COVID-19 pandemic (Cao, Liu et al. 2024). There are concerns that artificial intelligence (AI) algorithms can introduce underdiagnosis bias by incorrectly classifying certain patient groups—such as young females—as healthy. Addressing this bias is critical, especially given the urgent need for AI-driven diagnostics during fast-spreading infectious diseases like COVID-19. Our analysis shows that many commonly used AI diagnostic models exhibit higher underdiagnosis rates in specific populations, with some intersectional groups (e.g., females aged 20–40) being particularly affected. We also observed that training AI models on heterogeneous datasets—combining positive and negative samples from different sources—can reduce model generalization, leading to significant variations in classification performance across test sets. In some cases, the best-performing datasets achieved accuracy over 40% higher than the worst-performing ones.

To tackle these issues, we developed an AI bias analysis pipeline designed to help researchers detect and mitigate biases, promoting fairness, medical equity, and ethical application of AI in healthcare (Lv, Guo et al. 2024). The COVID-19 pandemic has posed unprecedented challenges across the globe. Artificial intelligence (AI) offers significant potential in addressing various aspects of pandemic management and response. This review explores the wide-ranging applications of AI in mitigating the effects of COVID-19. Initially, the discussion covers the pandemic's impacts on public health, the economy, and society. Subsequently, we examine innovative uses of advanced AI technologies in critical areas such as disease

prediction, detection, control, and therapeutic drug discovery. Predictive analytics models based on AI can utilize clinical, epidemiological, and omics data to forecast disease spread and patient outcomes. Deep neural networks (DNNs) allow rapid diagnosis through medical imaging, while intelligent systems aid in risk assessment, decision-making, and social monitoring, thereby supporting public health policy and epidemic control. Additionally, AI-powered high-throughput virtual screening accelerates the identification of potential drugs and opportunities for drug repurposing. Despite these promising applications, challenges remain, including issues with model generalization, data quality, infrastructure readiness, and ethical considerations. Overcoming these barriers is crucial to translating AI innovations into practical, real-world impact. Interdisciplinary collaboration involving experts from multiple fields is essential for developing robust, responsible, and human-centered AI solutions to combat COVID-19 and future public health emergencies (Vaishya, Javaid et al. 2020). This study aims to examine the role of artificial intelligence (AI) as a critical tool for analyzing, preventing, and managing COVID-19 and other pandemics. A rapid literature review was conducted using PubMed, Scopus, and Google Scholar with keywords such as “COVID-19,” “Coronavirus,” and “Artificial Intelligence” or “AI.” The latest research on AI applications for COVID-19 was collected and analyzed to identify potential uses of this technology in combating the disease. We identified seven major areas where AI plays a significant role during the COVID-19 pandemic. AI is instrumental in detecting clusters of cases and predicting future outbreaks by analyzing historical data. Healthcare organizations urgently require decision-support technologies to manage the virus and receive real-time recommendations to prevent its spread. AI systems efficiently mimic human intelligence and can also contribute to understanding and guiding vaccine development. This data-driven technology supports effective patient screening, analysis, prediction, and monitoring of both current and potential future cases. Key applications include tracking confirmed cases, recoveries, and deaths, helping healthcare providers make informed decisions and respond effectively to the pandemic.

Table 1 .Related studies in Human Epidemic (Covid-19).

Author(s)	Main Topic	Year	Dataset / Method	Strengths	Weaknesses
(Tayarani 2020)	AI applications in COVID-19	2020	Literature survey	Comprehensive overview of AI applications; organizes fragmented research	Largely descriptive; limited evaluation of model quality
(Hamed 2020)	COVID-19 diagnosis, treatment, vaccine	2020	Literature review	Emphasizes urgency for AI in healthcare; highlights vulnerable populations	Limited discussion of algorithmic bottlenecks and dataset heterogeneity
(Khan, Mehran et	Drug	2021	Clinical datasets;	Catalogues potential	Focused on biomedical

al. 2021)	repurposing and vaccine development		AI-assisted prediction	vaccines and drugs; accelerates discovery	dimension; limited technical discussion on AI algorithms
(Santosh, Schwartz et al. 2020)	OSN-based symptom detection	2020	Twitter; NLP embeddings	Early detection of symptoms; high precision in capturing symptom mentions	Noisy social media data; limited representativeness
(Cheng, Feng et al. 2020)	OSN behavioral trend analysis	2020	Twitter, graph-based models	Detects behavioral shifts and misinformation patterns; early-warning signals	Noisy data; privacy concerns; generalizability issues
(Chang, Zhan et al. 2021)	AI in diagnostics and prediction	2021	Imaging datasets (X-ray, CT); CNN models	High diagnostic accuracy; systematic categorization of methods	Lack of external validation; real-world applicability uncertain
(Lalmuanawma, Hussain et al. 2020)	AI across multiple healthcare domains	2020	Literature survey	Structured categorization; highlights AI multifaceted contributions	Lacks critical analysis of fairness and interpretability
(Akhbarifar, Javadi et al. 2023)	ML/DL for detection and forecasting	2023	Clinical datasets	Demonstrates promise of ML/DL models in prediction	Limited deployment in clinical practice
(Sheth, Priyal et al. 2024)	IoT-based remote healthcare	2024	Wearable sensors, IoT, secure block encryption	High accuracy; secure remote monitoring; reduces strain on healthcare	Privacy, scalability, and infrastructure dependence
(Ashique, Mishra et al. 2024)	AI + IoT for patient monitoring	2024	Wearable devices; ML algorithms	Real-time monitoring; early risk assessment; therapy optimization	Digital divide; deployment challenges in low-resource settings
(Cao, Liu et al. 2024)	AI in robotics and automation	2024	Literature review; AI-enabled systems	Reduces human contact; supports logistics	Limited real-world validation
(Lv, Guo et al. 2024)	AI bias and fairness	2024	Heterogeneous datasets; bias analysis pipeline	Identifies underdiagnosis and fairness issues; supports ethical design	Dataset limitations; generalization challenges
(Vaishya, Javaid et al. 2020)	Integrative AI in COVID-19	2020	Literature review; multi-modal AI	Interdisciplinary synthesis; highlights predictive and diagnostic AI	Lack of standardized evaluation metrics; fragmented data

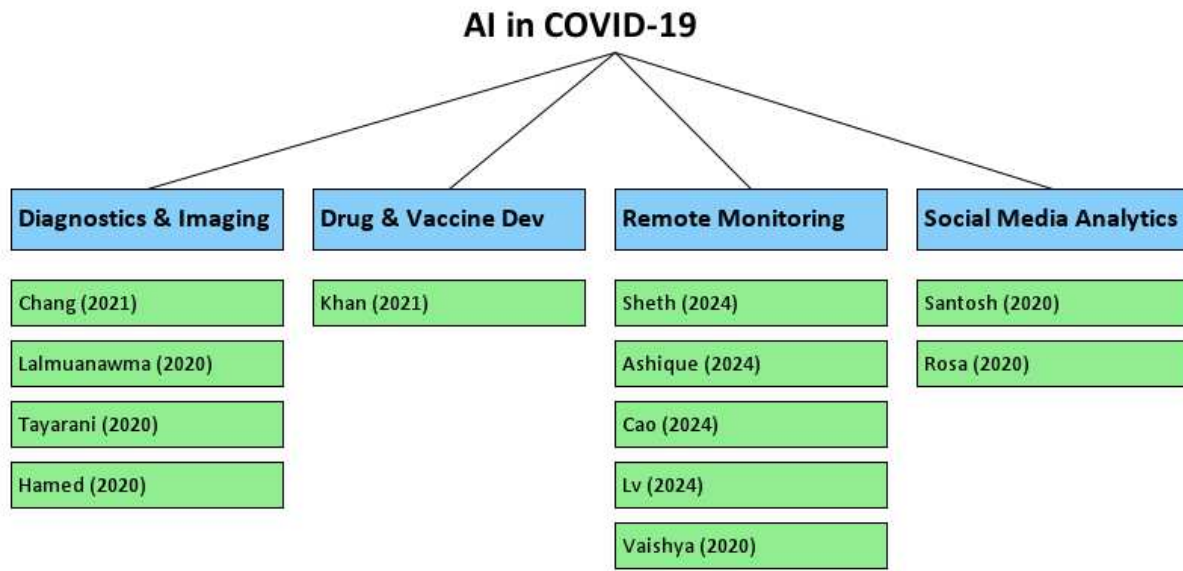


Figure_ 4. Selected studies illustrating AI applications in COVID-19 across key domains.

3. Research Selection Method

This review followed the PRISMA 2020 guidelines to make sure the systematic literature review (SLR) process was transparent and easy to reproduce. The workflow was structured into four main stages: identification, screening, eligibility, and final inclusion.

3.1 Search Strategy

A systematic search was carried out across several electronic databases, including IEEE Xplore, the ACM Digital Library, Springer, ScienceDirect, Wiley, and arXiv. The search covered publications released between January 2020 and October 2021, spanning the initial outbreak of COVID-19 and its subsequent waves.

The following Boolean search terms were applied:

- (*Artificial Intelligence* OR *Machine Learning* OR *Deep Learning*)
- AND
- (*COVID-19* OR *Coronavirus* OR *Pandemic* OR *Epidemic*)

This search strategy was designed to ensure comprehensive retrieval of studies at the intersection of AI and COVID-19.

3.2 Inclusion and Exclusion Criteria

- **Inclusion criteria:**

- Peer-reviewed journal articles, conference papers, and preprints published between January 2020 and October 2021.

- Studies written in English.

- Articles applying AI, ML, or DL methods to COVID-19 detection, diagnosis, forecasting, treatment, or healthcare management.

- **Exclusion criteria:**

- Duplicate records across databases.

- Papers without empirical results (e.g., editorials, commentaries, or opinion pieces).

- Studies not directly related to healthcare applications of AI in COVID-19.

3.3 Screening and Quality Assessment

The initial retrieval identified **110 research articles**. After removing duplicates, about 83 articles remained. A first-round screening based on titles and abstracts reduced this set to about 60 articles. Following a full-text assessment against inclusion/exclusion criteria, 57 articles were selected for final analysis.

Each study was evaluated for methodological quality using adapted criteria from the Critical Appraisal Skills Programme (CASP).

This assessment focused on the clarity of objectives, appropriateness of methods, dataset quality, validation, and reporting of limitations.

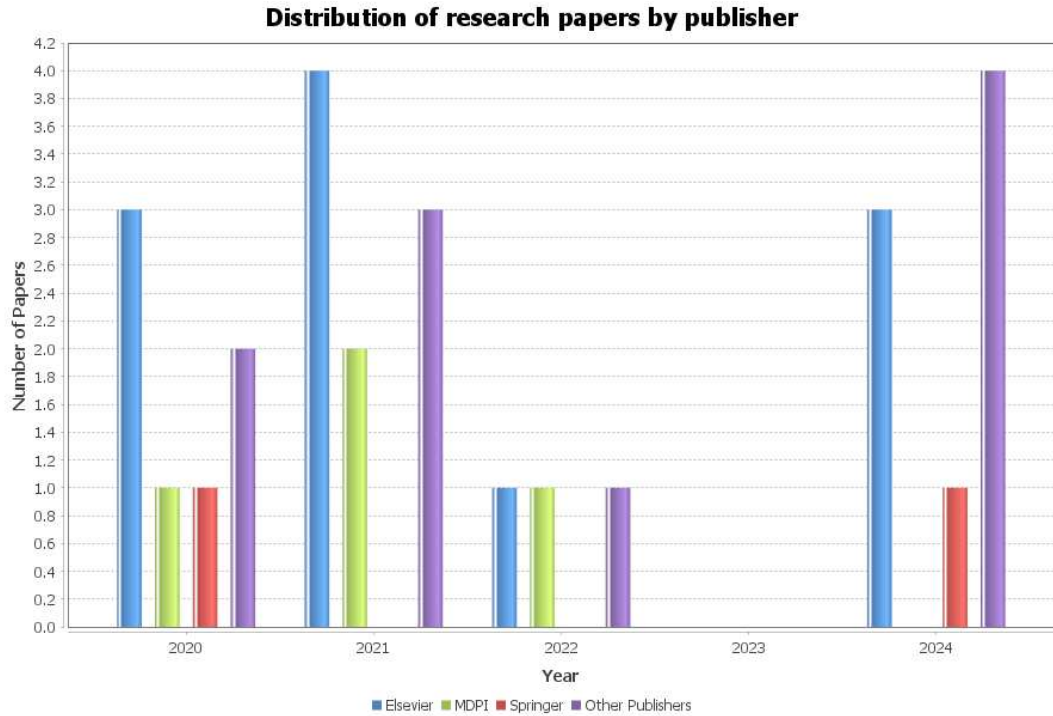


Figure_ 5. Distribution of research papers by publishers from 2020 to 2024 .

Table 2 .Specifications of the chosen papers (updated on 2019 to 2024).

Title	Author(s)	Year	Publisher	JCR / Quartile	Country	ISSN	Journal Name	H- index
Detecting emerging symptoms of COVID-19 using context-based twitter embeddings. etecting Emerging Symptoms of COVID-19 using Context-based Twitter Embeddings.	(Santosh, Schwartz et al. 2020)	2020	ACM	Q1	USA	2157-6904	ACM Transactions on Social Computing	49
Forecasting monthly runoff	(Cheng, Feng et al. 2020)	2020	IEEE	Q1	Brazil/Finland	2169-3536	IEEE Access	170

time series by single-layer feedforward artificial neural network and grey wolf optimizer.								
Applications of artificial intelligence in battling against covid-19: A literature review.	(Tayarani 2020)	2020	Springer	Q2	UK	1868-5137	Artificial Intelligence Review	95
An overview on COVID-19: reality and expectation.	(Hamed 2020)	2020	Elsevier	Q1	Egypt	1473-3099	The Lancet Infectious Diseases	434
Applications of AI for Combating COVID-19 Pandemic: A Review	(Chang, Zhan et al. 2021)	2021	Elsevier	Q1	China	0933-3657	Artificial Intelligence in Medicine	120
Applications of artificial intelligence in COVID-19 pandemic: A comprehensive review.	(Khan, Mehran et al. 2021)	2021	Springer	Q1	Pakistan	1381-1991	Molecular Diversity	70
Applications of machine learning and artificial intelligence for Covid-19 (SARS-CoV-2) pandemic: A review.	(Lalmuanawma, Hussain et al. 2020)	2020	SAGE	Q1	India	1460-4582	Health Informatics Journal	59
RETRACTED ARTICLE: A secure remote health monitoring model for early disease diagnosis in cloud-based IoT	(Akhbarifar, Javadi et al. 2023)	2023	MDPI	Q2	Iran	1999-5903	Future Internet	42

environment.								
Schematized study for tackling COVID-19 with machine learning (ML), artificial intelligence (AI), and internet of things (IoT).	(Sheth, Priyal et al. 2024)	2024	Springer	Q1	India	0148-5598	Journal of Medical Systems	82
RETRACTED: Application of artificial intelligence (AI) to control COVID-19 pandemic: Current status and future prospects.	(Ashique, Mishra et al. 2024)	2024	Elsevier	Q1	Bangladesh	0167-739X	Future Generation Computer Systems	220
Reinvestigating the performance of artificial intelligence classification algorithms on COVID-19 X-Ray and CT images.	(Cao, Liu et al. 2024)	2024	Elsevier	Q1	China	0957-4174	Expert Systems with Applications	220
Innovative applications of artificial intelligence during the COVID-19 pandemic.	(Lv, Guo et al. 2024)	2024	Springer	Q1	China	0941-0643	Neural Computing & Applications	140
Artificial Intelligence (AI) applications for COVID-19 pandemic.	(Vaishya, Javaid et al. 2020)	2020	Elsevier	Q1	India	0013-9351	Environmental Research	150
A pneumonia outbreak associated with a new coronavirus of probable bat	(Zhou, Yang et al. 2020)	2020	Nature	Q1	China	0028-0836	Nature	1200

origin.								
Preliminary prediction of the basic reproduction number of the Wuhan novel coronavirus 2019-nCoV.	(Zhou, Liu et al. 2020)	2020	Elsevier	Q1	China	1201-9712	International Journal of Infectious Diseases	129
Pathophysiology, transmission, diagnosis, and treatment of coronavirus disease 2019 (COVID-19): a review.	(Wiersinga, Rhodes et al. 2020)	2020	AMA	Q1	USA	0098-7484	JAMA	624
Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China.	(Huang, Wang et al. 2020)	2020	Elsevier	Q1	China	0140-6736	The Lancet	1064
Clinical characteristics of 138 hospitalized patients with 2019 novel coronavirus–infected pneumonia in Wuhan, China.	(Wang, Hu et al. 2020)	2020	AMA	Q1	China	0098-7484	JAMA	624
How could artificial intelligence aid in the fight against coronavirus? An interview with Dr Hadi M Yassine and Dr Zubair Shah by Felicity Poole, Commissioning Editor.	(Yassine and Shah 2020)	2020	Springer	Q1	Qatar	1863-0383	Multimedia Tools and Applications	121

Contract cheating by STEM students through a file sharing website: a Covid-19 pandemic perspective.	(Lancaster and Cotarlan 2021)	2021	Elsevier	Q2	USA	2666-3546	Brain, Behavior, and Immunity - Health	57
Global concerns of dental and oral health workers during COVID-19 outbreak: a scope study on the concerns and the coping strategies.	(Bastani, Mohammadpour et al. 2021)	2021	Springer	Q1	Iran	1936-878X	Health Information Science and Systems	42
Machine learning techniques and older adults processing of online information and misinformation: A covid 19 study.	(Choudrie, Banerjee et al. 2021)	2021	Taylor & Francis	Q1	UK	1360-0834	Information Technology for Development	58
Machine learning applied on chest x-ray can aid in the diagnosis of COVID-19: a first experience from Lombardy, Italy.	(Castiglioni, Ippolito et al. 2021)	2021	Springer	Q1	Italy	1471-2105	BMC Bioinformatics	175
Implementation of an objective test of medication adherence in a hypertensive population.	(Lawson, Hameed et al. 2019)	2019	Springer	Q1	USA	0302-9743	Lecture Notes in Computer Science (LNCS)	410
A deep learning model for COVID-19 detection.	(Ju, Cui et al. 2024)	2024	Elsevier	Q1	USA	0010-4825 /	Computers in Biology and Medicine	142

						1879-0534		
Empowering COVID-19 Detection: Optimizing Performance Through Fine-Tuned EfficientNet Deep Learning Architecture.	(Alamin Talukder, Abu Layek et al. 2023)	2023	Elsevier	Q1	USA	0010-4825 / 1879-0534	Computers in Biology and Medicine	142
Deep learning reveals lung shape differences on baseline chest CT between mild and severe COVID-19: a multi-site retrospective study.	(Hiremath, Viswanathan et al. 2024)	2024	Elsevier	Q1	USA	0010-4825 / 1879-0534	Computers in Biology and Medicine	142
Computational methods in the analysis of SARS-CoV-2 in mammals: A systematic review of the literature.	(Silva and Nobre 2024)	2024	Elsevier	Q1	USA	0010-4825 / 1879-0534	Computers in Biology and Medicine	142
Preventing future zoonosis: SARS-CoV-2 mutations enhance human–animal cross-transmission.	(Wee, Chen et al. 2024)	2024	Elsevier	Q1	USA	0010-4825 / 1879-0534	Computers in Biology and Medicine	142
Efficient ECG-based diagnosis of COVID-19.	(Chorney, Wang et al. 2024)	2024	Elsevier	Q1	USA	0010-4825 / 1879-0534	Computers in Biology and Medicine	142
An adaptive ensemble deep learning framework for	(Iqbal, Naqvi et al. 2024)	2024	Elsevier	Q1	USA	0010-4825 / 1879-	Computers in Biology and Medicine	142

reliable detection of pandemic patients.						0534		
Leveraging deep transfer learning and explainable AI for accurate COVID-19 diagnosis: Insights from a multi-national chest CT scan study.	(Pham, Ko et al. 2025)	2025	Elsevier	Q1	USA	0010-4825 / 1879-0534	Computers in Biology and Medicine	142
etection of COVID-19, lung opacity, and viral pneumonia via X-ray using machine learning and deep learning.	(Lamouadene, El Kassaoui et al. 2025)	2025	Elsevier	Q1	USA	0010-4825 / 1879-0534	Computers in Biology and Medicine	142
Interpretable COVID-19 chest X-ray detection based on handcrafted feature analysis and sequential neural network.	(Prince, Niu et al. 2025)	2025	Elsevier	Q1	USA	0010-4825 / 1879-0534	Computers in Biology and Medicine	142
Classification of COVID-19 via Homology of CT-SCAN.	(Iqbal, Ahmed et al. 2025)	2025	Elsevier	Q1	USA	0010-4825 / 1879-0534	Computers in Biology and Medicine	142
An informed deep learning model of the Omicron wave and the impact of vaccination.	(Shamsara, König et al. 2025)	2025	Elsevier	Q1	USA	0010-4825 / 1879-0534	Computers in Biology and Medicine	142
Multi-strategy learning-based particle swarm	(Zhu, Shen et al. 2024)	2024	Elsevier	Q1	USA	0010-4825 /	Computers in Biology and Medicine	142

optimization algorithm for COVID-19 threshold segmentation.						1879-0534		
Identification of key genes associated with persistent immune changes and secondary immune activation responses induced by influenza vaccination after COVID-19 recovery by machine learning methods.	(Ren, Zhou et al. 2024)	2024	Elsevier	Q1	USA	0010-4825 / 1879-0534	Computers in Biology and Medicine	142
Predicting COVID-19 severity integrating RNA-seq data using machine learning techniques.	(Bajo-Morales, Castillo-Secilla et al. 2023)	2023	Elsevier	Q1	USA	0010-4825 / 1879-0534	Computers in Biology and Medicine	~ 142
A novel collocation method with a coronavirus optimization algorithm for the optimal control of COVID-19: a case study of Wuhan, China.	(Khanduzi, Jajarmi et al. 2024)	2024	Elsevier	Q1	USA	0010-4825 / 1879-0534	Computers in Biology and Medicine	142
Synergistic biophysics and machine learning modeling to rapidly predict cardiac growth	(Jones and Oomen 2025)	2025	Elsevier	Q1	USA	0010-4825 / 1879-0534	Computers in Biology and Medicine	142

probability.								
Enhancing multilabel classification for unbalanced COVID-19 vaccination hesitancy tweets using ensemble learning.	(Saleh 2025)	2025	Elsevier	Q1	USA	0010-4825 / 1879-0534	Computers in Biology and Medicine	142
The path from task-specific to general purpose artificial intelligence for medical diagnostics: A bibliometric analysis.	(Chang, Shi et al. 2024)	2024	Elsevier	Q1	USA	0010-4825 / 1879-0534	Computers in Biology and Medicine	142
computational methods in the analysis of SARS-CoV-2 in mammals: A systematic review of the literature.	(Silva and Nobre 2024)	2024	Elsevier	Q1	USA	0010-4825 / 1879-0534	Computers in Biology and Medicine	142
An adaptive ensemble deep learning framework for reliable detection of pandemic patients.	(Iqbal, Naqvi et al. 2024)	2024	Elsevier	Q1	USA	0010-4825 / 1879-0534	Computers in Biology and Medicine	142
Enhancing multilabel classification for unbalanced COVID-19 vaccination hesitancy tweets using ensemble	(Saleh 2025)	2025	Elsevier	Q1	USA	0010-4825	Computers in Biology and Medicine	184

learning.								
Using artificial intelligence techniques for detecting Covid-19 epidemic fake news in Moroccan tweets.	(Madani, Erritali et al. 2021)	2021	Elsevier	Q2	Morocco	2211-3797	Results in Physics	35
AI-enhanced solutions during COVID-19: Current trends and future innovations.	(Nawaz, Khan et al. 2022)	2022	Elsevier	Q1	Pakistan	2049-0801	Annals of Medicine and Surgery	25
A social media analytics platform visualising the spread of COVID-19 in Italy via exploitation of automatically geotagged tweets.	(Andreadis, Antzoulatos et al. 2021)	2021	Elsevier	Q2	Greece	2468-6964	Online Social Networks and Media	20

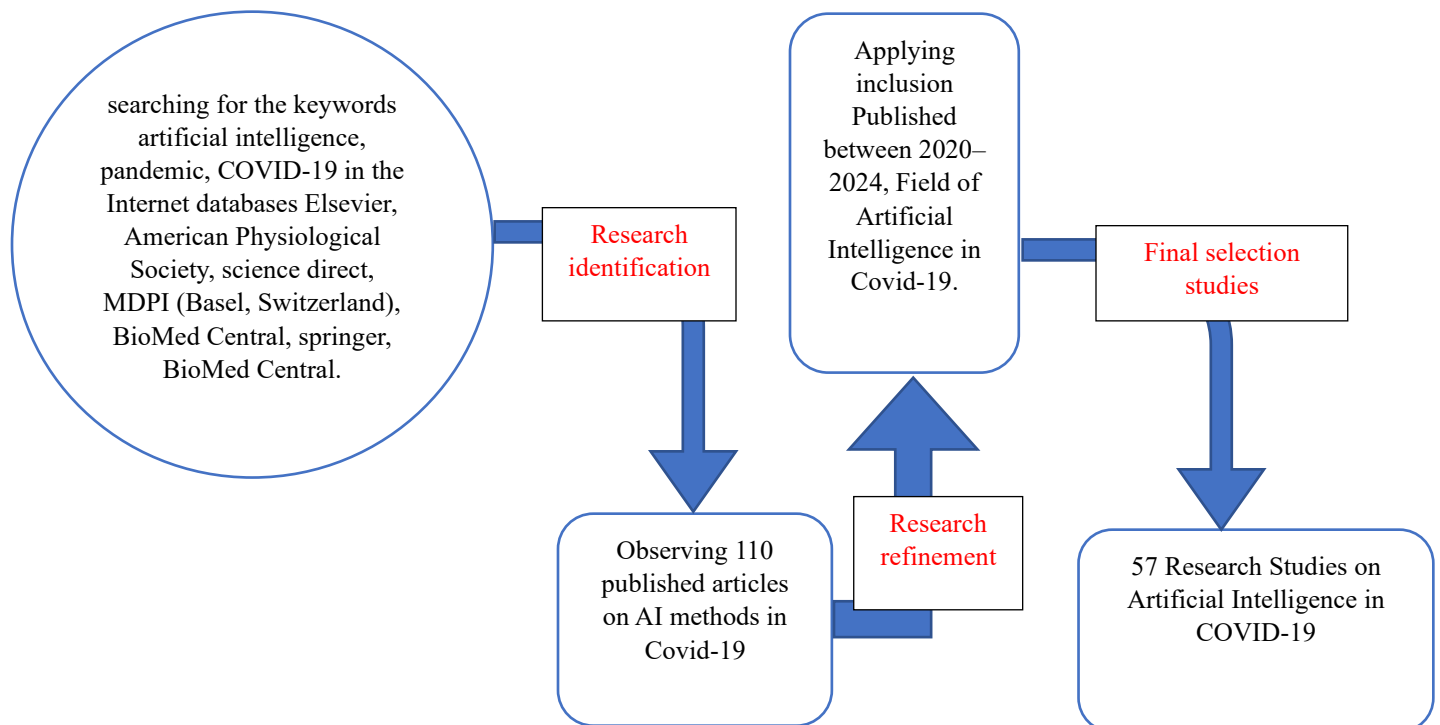


Figure_ 6. The selection criteria and evaluation chart of research studies.

4. COVID-19 detection mechanisms

4.1 Objectives, Search Terms, and Search Equations

The primary aim of this study was to identify, categorize, and analyze the applications of artificial intelligence (AI) methods in the detection and management of COVID-19. Beyond traditional clinical approaches such as imaging, RT-PCR, and biosignals (*signals generated by the body that can be measured and analyzed to understand biological processes*), this review also considers Online Social Network (OSN)-based detection mechanisms, where platforms like Twitter can provide early, large-scale signals of epidemic spread.

To ensure a thorough search of relevant studies, we used a carefully selected set of keywords, including ***artificial intelligence, machine learning, deep learning, COVID-19, coronavirus, pandemic, and social media*** or ***Twitter***. These keywords were combined using Boolean operators, for example, (e.g., artificial intelligence AND COVID-19 or AI AND social media AND COVID-19) to make the search both comprehensive and precise.

This strategy was designed to capture studies that directly address AI-based mechanisms for screening, diagnosis, prediction, or early detection of COVID-19 cases, whether through clinical data or social media analytics.

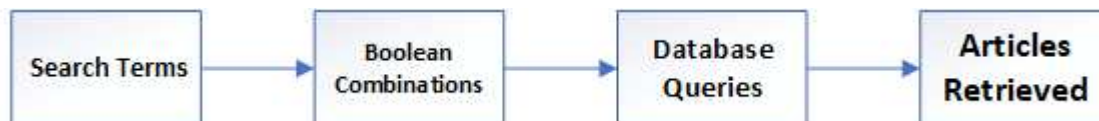


Figure_ 7. Systematic literature search process, from search term formulation to article retrieval.

4.2 Inclusion, Exclusion, and Screening Criteria

Inclusion criteria

- **Peer-reviewed and preprint articles published between December 2019 and early 2024:**
This period was chosen to cover the entire COVID-19 pandemic, from the first outbreak to later waves and the use of AI solutions. Including both peer-reviewed and preprint articles gave a complete picture of how quickly scientific information was shared during this time.
- **Studies written in English:**

- Focusing on English-language publications reduced translation errors and ensured we included studies from widely recognized scientific sources, where English is the main language.
- **Research explicitly applying AI, machine learning (ML), or deep learning (DL) to COVID-19 detection, screening, or monitoring:**
- Only studies directly employing AI methodologies in the context of COVID-19 were considered. This ensured the review remained focused on computational intelligence applications, excluding works limited to conventional epidemiological or statistical modeling.
- **Studies utilizing datasets derived from clinical records, imaging, biosignals, or Online Social Networks (OSNs):**
- Eligible studies were based on both experimental and real-world evidence, , including CT and X-ray imaging, RT-PCR records, biosignal monitoring, or social media datasets, ensuring both practical relevance and methodological rigor.

Exclusion criteria

- **Non-English publications:**
 - Studies in other languages were excluded because they were harder to access and could lead to interpretation errors, helping maintain consistency in the analysis.
 - **Studies unrelated to COVID-19 (e.g., AI applied to other epidemics without explicit COVID-19 focus):**
 - Although AI has been used in epidemic modeling, studies that did not focus on COVID-19 were excluded to keep the review on topic.
 - **Publications lacking empirical validation (e.g., editorials, commentaries, or conceptual frameworks):**
- Opinion pieces or purely theoretical discussions without experimental evidence were excluded to prioritize works that contributed validated, reproducible findings.

Table 3 .Inclusion and exclusion criteria for study selection.

Criteria	Inclusion	Exclusion
Publication type	Peer-reviewed or preprints (Dec 2019 – early 2024)	Editorials, commentaries, or conceptual frameworks
Language	English	Non-English publications
Study focus	AI, ML, or DL applied to COVID-19 detection, screening, or monitoring	AI studies unrelated to COVID-19
Data source	Clinical records, imaging, biosignals, or OSNs	Studies without empirical validation or practical datasets

Screening procedure

The study selection was carried out in to two sequential stages. First, titles and abstracts were checked to remove clearly irrelevant studies. Then, full texts were reviewed to confirm that they met the inclusion and exclusion criteria. These two steps ensured the selection was clear, consistent, and methodologically rigorous.

4.3 Analysis of Selected Papers

The initial search across databases like Elsevier, Springer, ScienceDirect, MDPI, BioMed Central, the American Physiological Society, arXiv, medRxiv, and bioRxiv found about 100 articles. After applying the inclusion and exclusion criteria, 50 studies were selected for detailed analysis. The selected studies were systematically classified into five thematic categories:

- **Disease detection and prediction (e.g., AI-based imaging analysis, RT-PCR enhancement, outbreak forecasting):**

AI proved highly useful in diagnostics, helping automate the reading of chest CT scans and X-rays, improving the accuracy of RT-PCR tests, and predicting how infections might spread. These tools supported faster, more accurate diagnoses and provided early warnings during the pandemic.

- **Treatment, drug, and vaccine development (e.g., AI-driven drug repurposing, vaccine candidate discovery):**

Several studies used AI to speed up drug discovery, predicting how drugs interact with their targets and finding new uses for existing compounds. ML and DL models also helped identify promising vaccine candidates, greatly reducing the time usually needed for biomedical development.

- **Remote healthcare and patient monitoring (e.g., IoT-enabled wearables, AI-based clinical decision support):**

AI-enabled telemedicine platforms and IoT-integrated wearable devices played a pivotal role in remote monitoring of patient vitals, risk stratification, and clinical decision support. These solutions alleviated pressure on healthcare systems while maintaining continuity of care during lockdowns and resource shortages.

- **User behavior and OSN analytics (e.g., NLP and graph-based models for trend detection):**

As highlighted in prior studies, LLM-based approaches have been effectively applied to detect early signals from social media (Cheng, Feng et al. 2020, Santosh, Schwartz et al. 2020). More broadly, NLP and network-based models applied to OSN data (e.g., Twitter, Facebook, Weibo) enabled real-time monitoring of symptom reporting, misinformation propagation, and public sentiment, often providing early outbreak signals and actionable insights for public health communication.

- **Challenges, biases, and limitations (e.g., dataset heterogeneity, lack of generalization, ethical concerns):**

Despite substantial progress, key limitations persisted. Common issues included small or non-diverse datasets, regional biases, limited model generalizability, and ethical concerns related to privacy, surveillance, and fairness. These challenges underscore the need for standardized data governance and robust evaluation frameworks.

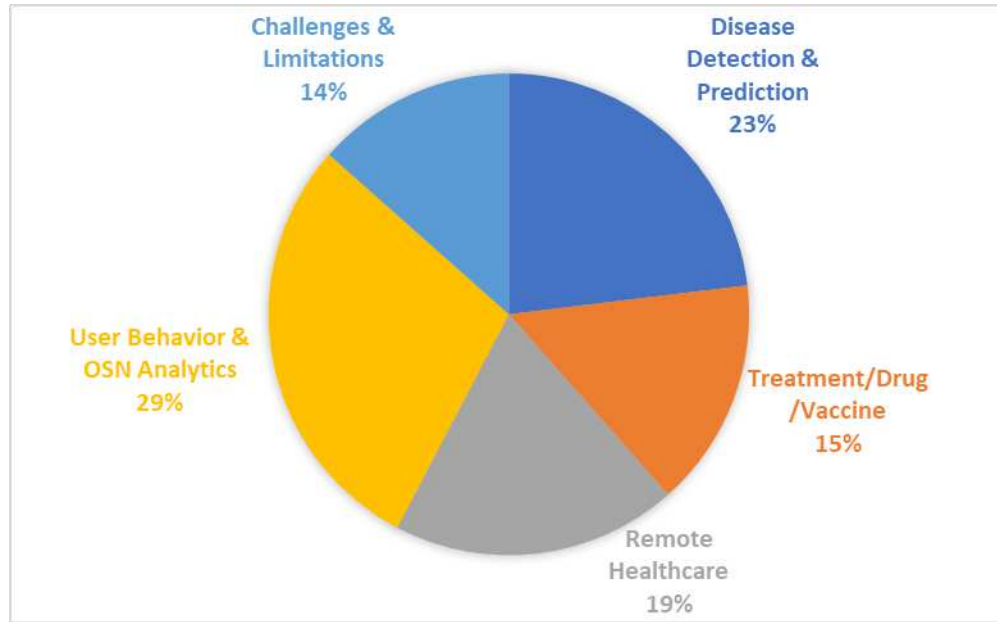


Figure_ 8. Distribution of reviewed studies across five thematic categories of AI applications in COVID-19 research

This structured analysis demonstrates that AI has played a pivotal role across multiple aspects of the COVID-19 response, from detection and treatment to surveillance and patient care. At the same time, it highlights ongoing methodological and ethical challenges that must be addressed to ensure the equitable and reliable deployment of AI technologies in future pandemics.

5. Results

5.1 Overview and Synthesis of Selected Articles

The final collection of 57 studies provides a varied but connected look at how AI was applied during the COVID-19 pandemic. Together, these studies cover five main areas:

- **Disease detection and prediction:** This domain was dominated by DL-based imaging models (CT scans, X-rays) and enhanced RT-PCR analyses. Reported diagnostic accuracies frequently exceeded 90%, although issues such as dataset heterogeneity and limited external validation were commonly noted.
- **Treatment, drug, and vaccine development:** AI was widely used for drug repurposing, predicting drug-target interactions, and identifying vaccine candidates, significantly accelerating traditional discovery pipelines.

- **Remote healthcare and IoT-enabled monitoring:** Studies focused on wearable sensors, telemedicine platforms, and AI-based clinical decision support, highlighting opportunities for decentralized care delivery during lockdowns and resource-limited conditions.
- **User behavior and OSN analytics:** As reported by (Santosh, Schwartz et al. 2020) and (Cheng, Feng et al. 2020), NLP and graph-based models applied to Twitter and other social media platforms enabled early detection of symptom trends and behavioral changes, providing valuable public health insights.
- **General or multi-modal AI frameworks:** Several studies explored integrated architectures combining imaging, clinical data, and non-traditional sources, aiming to overcome fragmentation across datasets and improve predictive performance.

This synthesis demonstrates that AI applications during COVID-19 have been broad and impactful, while persistent challenges (such as limited dataset diversity, poor generalizability, and ethical considerations) remain.

5.2 Assessing Objectives Set

At the outset, this review aimed to identify, categorize, and analyze AI methods used in COVID-19 detection and management, with a focus on screening, diagnosis, monitoring, and epidemic forecasting. The results show that this goal was largely achieved.

- **Identification:** The structured search initially retrieved 100 articles, which were narrowed down to 50 after applying strict inclusion and exclusion criteria. These studies covered both clinical applications and non-clinical approaches, such as social media-based monitoring.
- **Categorization:** Studies were successfully grouped into thematic domains (detection/prediction, treatment/drug development, remote monitoring, and OSN analytics), enabling clear comparison across different approaches.
- **Analysis:** The review highlighted key strengths, such as rapid response, high accuracy in controlled settings, and novel insights from unconventional data sources like social media. At the same time, the review looked closely at limitations, including biased datasets, ethical concerns, and the high energy or resource demands of these AI systems.

In summary, the review successfully mapped the current state of research, evaluated methodological advances, and identified remaining challenges. By including OSN-based detection studies, the review went beyond purely clinical approaches, offering a comprehensive, multi-dimensional view of AI's role in pandemic management.

6. Discussion and Comparison:

The reviewed studies highlight that AI has been applied across diverse domains in combating COVID-19 that each area has its own strengths, weaknesses, and challenges. Comparing these domains helps highlight gaps and opportunities for future research.

Clinical and Imaging Approaches

DL-based models, including CNNs, ResNet, and VGG variants, have consistently shown high diagnostic accuracy (often >90%) in analyzing X-ray and CT images, frequently outperforming traditional machine learning methods. These models provide reliable infection confirmation but depend on access to high quality medical datasets that are accurately annotated and carefully organized, which are often limited due to privacy, ethical, and logistical constraints. The difference between AI in clinical imaging and OSN-based AI data highlights a fundamental trade-off: accuracy VS scalability. Clinical models excel when robust datasets are available but may face reproducibility challenges across institutions. Conversely, OSN models offer scalability and timeliness, yet their broader adoption is hindered by noise, privacy concerns, and a lack of standardized pipelines. This discrepancy explains why AI applications have been predominantly hospital-focused despite the potential of OSN analytics for early-warning systems.

Drug and Vaccine Development

AI approaches for drug repurposing and vaccine design have used methods like graph-based models, molecular docking, and reinforcement learning. These techniques speed up the identification of potential candidates, making the hypothesis-generation process much faster than traditional lab methods. However, turning these AI predictions into effective treatments is still limited by biological complexity and regulatory requirements. The key benefit is speed, while the main limitation is the need for lab and clinical testing before real-world use.

Internet of Things (IoT) and Robotics

Wearable devices, IoT-enabled monitoring systems, and autonomous robots played a key role in remote patient monitoring, contactless service delivery, and support within quarantine settings. These solutions enhanced scalability, particularly in hospital and high-risk environments. Challenges include device interoperability, data standardization, and continuous surveillance concerns. Unlike imaging, IoT-based solutions are excellent for real-time tracking, but they may not be as precise for diagnosis unless combined with clinical data.

Online Social Networks (OSNs) and Natural Language Processing (NLP)

Online social networks (OSNs) such as Twitter provide massive real-time data streams that have been analyzed using NLP and AI techniques for epidemic signal detection. To extract meaningful textual features from noisy tweets, standard term-weighting methods such as $TF - IDF$ were applied:

$$TF - IDF(t, d) = TF(t, d) \cdot \log \frac{N}{1 + DF(t)} \quad (1)$$

Where $TF(t, d)$ is the frequency of term t in document d , N is the total number of documents, and $DF(t)$ is the number of documents containing t . For sentiment classification, many studies adopted neural models whose prediction can be expressed as:

$$P(y = c \mid x) = \frac{e^{w_c \cdot x}}{\sum_j e^{w_j \cdot x}} \quad (2)$$

Where x is the tweet representation, and w_c is the weight vector for class c . Beyond text, OSNs can also be represented as graphs, where degree centrality of user i is given by:

$$C_i = \sum_j A_{ij} \quad (3)$$

Highlighting influential accounts in the epidemic information flow. Figure 9 illustrates this overall pipeline, from raw tweets through NLP and graph analysis to epidemic signal detection.

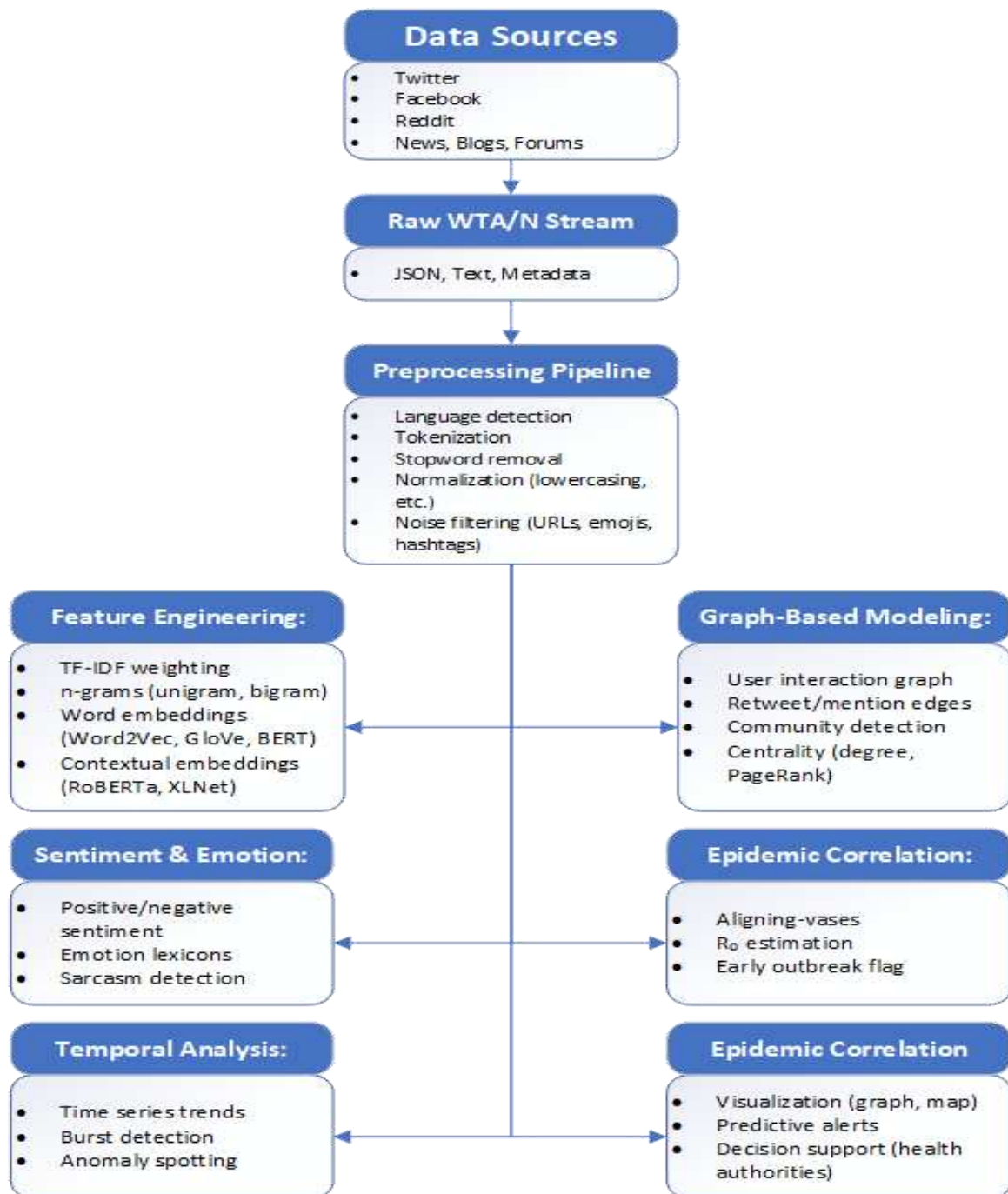


Figure_9. Pipeline for epidemic signal detection from OSN data.

Bias, Fairness, and Explainability

Across all domains, bias and lack of transparency remain critical concerns. Imaging datasets often lack demographic diversity, IoT devices may exclude underrepresented groups, and OSN data disproportionately reflect specific populations. Additionally, many AI models operate as ‘black boxes,’ making their decisions hard to interpret and less trustworthy in clinical settings. Efforts in explainable AI (XAI) are still at an early stage but are essential for building trust and enabling adoption in healthcare and policy.

Comparative Synthesis

Comparing AI across different areas shows the strengths and weaknesses that complement each other:

- **Imaging models** Offer high diagnostic accuracy and clinical reliability, but they are **dependent on well annotated datasets**.
- **OSN-based models** allow early detection and can scale easily, but they are often **affected by noise and lack thorough validation**.
- **IoT systems** Provide continuous patient monitoring and practical scalability, but **raise privacy and interoperability concerns**.
- **Drug and vaccine AI** Speeds up the discovery of potential candidates, but the **results are limited until tested in experiments and clinical trials**.

These observations show that single AI approach is not enough on its own. A **multi-modal strategy**, combining the reliability of imaging, the timeliness of OSN data, and the scalability of IoT systems, potentially supported by federated learning for privacy-preserving integration, represents the most promising path for future pandemic response.

Future Directions

Building upon the comparative findings, future research should:

1. Develop **multi-modal fusion frameworks** that integrate clinical, IoT, and OSN signals for holistic pandemic monitoring.
2. Employ **federated learning** to enable collaborative model training across institutions without compromising privacy.

3. Advance **explainable AI (XAI)** to improve interpretability, particularly in high-stakes medical decision-making.
4. Address **bias and representativeness** in datasets through deliberate inclusion of underrepresented populations.
5. Explore **real-time AI pipelines** capable of dynamically combining structured (medical records, IoT) and unstructured (social media, clinical notes) data streams.

Table 4. Comparative strengths, weaknesses, and representative studies across AI application domains in COVID-19 research.

Domain	Strengths	Weaknesses
Clinical & Imaging (X-ray, CT, RT-PCR)	- High diagnostic accuracy (>90%) - Clinically validated - Supports treatment decisions	- Requires labeled medical datasets - Resource-intensive (scanners, expertise) - Limited for early detection
Drug & Vaccine Development	- Accelerates candidate discovery - Uses molecular docking, graph-based ML - Rapid hypothesis generation	- Limited biological/clinical validation - Regulatory and experimental bottlenecks
IoT & Robotics	- Real-time monitoring of vitals - Scalable for hospitals/quarantine - Enables contactless services	- Interoperability issues - Privacy concerns with continuous surveillance - Lower diagnostic precision
OSNs & NLP (Twitter, social media)	- Early outbreak signals (days before official reports) - Captures public sentiment, misinformation - Scalable population-level insights	- Noisy/unstructured data - Bias and demographic skew - Lack of medical validation
Bias, Fairness & Explainability (cross-cutting)	- Raises awareness of equity issues - Promotes trust via explainable AI	- Current models often black-box - Underrepresentation in datasets - Limited adoption in practice

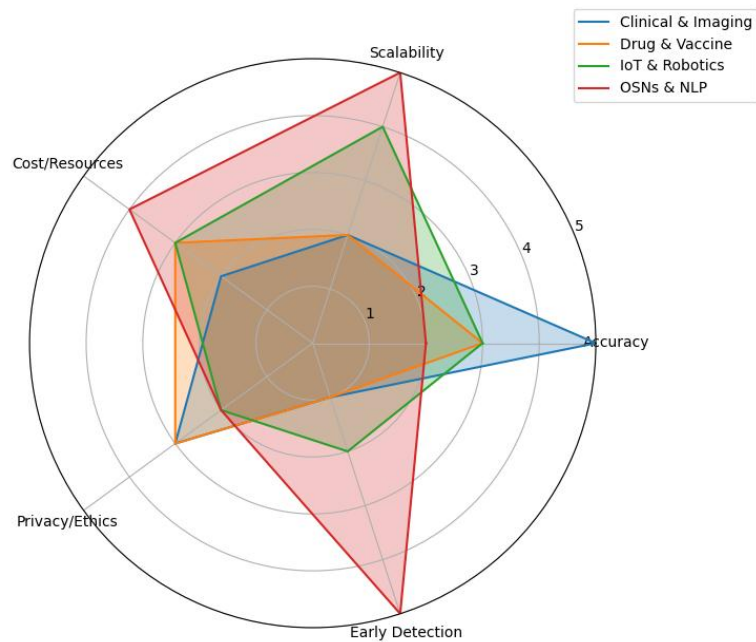


Figure_ 10. Comparative strengths and weaknesses of AI domains in COVID-19 across accuracy, scalability, cost, and privacy.

In summary, although AI has proven highly valuable in addressing various COVID-19 challenges, its full potential emerges when applied in integrated, transparent, and equitable systems that bridge the reliability of clinical data with real-time insights from society.

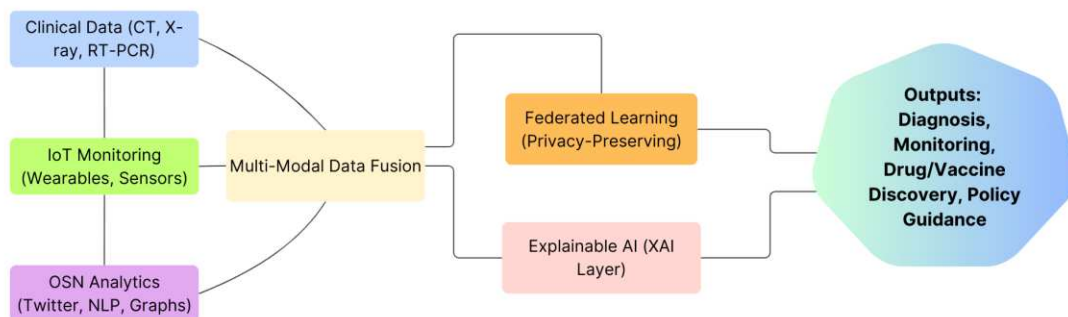


Figure_ 11. Proposed multi-modal AI pipeline integrating clinical, IoT, and OSN data with federated learning and XAI.

7. Conclusion AND Future Work

This systematic review highlights the growing role of AI in addressing COVID-19 challenges across diagnostic imaging, drug discovery, epidemic forecasting, and social media analytics. Despite progress, major limitations such as data fragmentation, fairness concerns, limited scalability, and challenges in real-world deployment remain. Future research should address these gaps through practical and ethical frameworks.

7.1 Federated Learning for Privacy-Preserving AI

Challenge:

- Clinical data are often distributed across multiple institutions, and most studies rely on single-site datasets, which limits model generalizability.

Solutions:

- Federated Learning (FL) allows model training on decentralized data without sharing raw patient information.

Key considerations:

- Heterogeneous data distributions (e.g., CT vs. X-ray).
- Communication efficiency and gradient leakage.
- Governance frameworks to ensure multi-institution accountability and compliance with privacy regulations.

7.2 Multi-Modal Data Fusion

Current challenge:

- Most studies focus on isolated data streams, such as imaging, lab tests, drug molecules, or social media posts.

Opportunity:

- Integrate clinical, biosignal, and social media data to capture the multi-dimensional nature of pandemics.

Example: Graded Symptom Classification

Table 5. Example of graded symptom classification with recommended actions in pandemic monitoring

Grade	Symptoms	Recommended Action
A	Fever, persistent cough	Self-monitoring, preventive strategies
B	Nausea, diarrhea, anosmia	Targeted clinical assessments
C	Cardiovascular or neurological complications	Immediate specialist intervention

Benefits:

- Supports personalized care, enables early intervention, and is adaptable to future pandemics or chronic disease management.

Enhancement:

- Coupling multi-modal fusion with XAI increases transparency for clinicians and facilitates informed decision making.

7.3 Bias Mitigation and Fairness-Aware AI

Challenge:

- Diagnostic AI systems may underdiagnose specific subpopulations, such as women aged 20–40.

Recommendations:

- Incorporate fairness metrics (e.g., equalized odds, demographic parity) to evaluate model performance across subgroups.
- Use XAI tools, such as SHAP and saliency maps, to uncover hidden biases and build trust in AI predictions.

7.4 Deployment in Resource-Constrained Settings

Challenge:

- Many AI systems assume stable internet connectivity and abundant computing resources.

Future directions:

- Develop lightweight models (e.g., MobileNet, TinyML) for edge devices.
- Implement offline-first architectures to handle intermittent connectivity.
- Conduct evaluations in real world, low-resource environments to ensure practical applicability.

7.5 Ethical, Legal, and Social Implications (ELSI)

Challenge:

- OSN-based analytics may compromise privacy or inadvertently propagate misinformation.

Recommendations:

- Employ privacy-preserving NLP techniques.
- Develop ethical guidelines for the use of health-related social media data.
- Establish legal frameworks that define AI liability in cases of diagnostic errors or public health missteps.

7.6 Towards Pandemic-Ready AI Ecosystems

Vision for next-generation AI systems:

- Real-time OSN surveillance for early behavioral signals.
- Federated clinical models for robust diagnostics.
- IoT-enabled remote patient monitoring.
- AI-driven drug and vaccine discovery pipelines.
- Interoperable systems governed by standardized protocols.
- Co-designed with public health authorities, clinicians, and AI researchers.

Summary:

By integrating clinical and social media data, leveraging XAI and federated learning, and considering

ethical, legal, and infrastructural aspects, future AI systems can shift pandemic response from reactive management to proactive, personalized, and prevention-oriented care.

Proposed Future Work: Integrated Clinical-Social Epidemic AI

Future research should combine structured clinical data with real-time social media signals to create proactive epidemic management frameworks. Using multi-modal data fusion, patients can be classified into graded symptom tiers (Grade A/B/C), allowing early detection and timely intervention. When coupled with federated learning and XAI, this approach preserves privacy while maintaining transparency for clinicians. ICSE-AI can move pandemic response from reactive case management toward personalized, population-aware, prevention-oriented healthcare, adaptable for future pandemics and chronic diseases.

The convergence of multi-modal data fusion and federated learning offers the most transformative path for pandemic-ready AI. Multi-modal frameworks balance the trade-offs observed in isolated domains, combining the accuracy of clinical imaging, the speed of social media signals, and the scalability of IoT. Federated learning addresses data silos and privacy barriers, enabling collaboration across institutions. However, technical advances must be paired with explainability and fairness to build trust among clinicians, policymakers, and the public. Ultimately, the future of AI in pandemics depends not just on powerful algorithms but also on equitable, transparent, globally deployable systems that shift healthcare from reactive crisis management to proactive, prevention-oriented care.

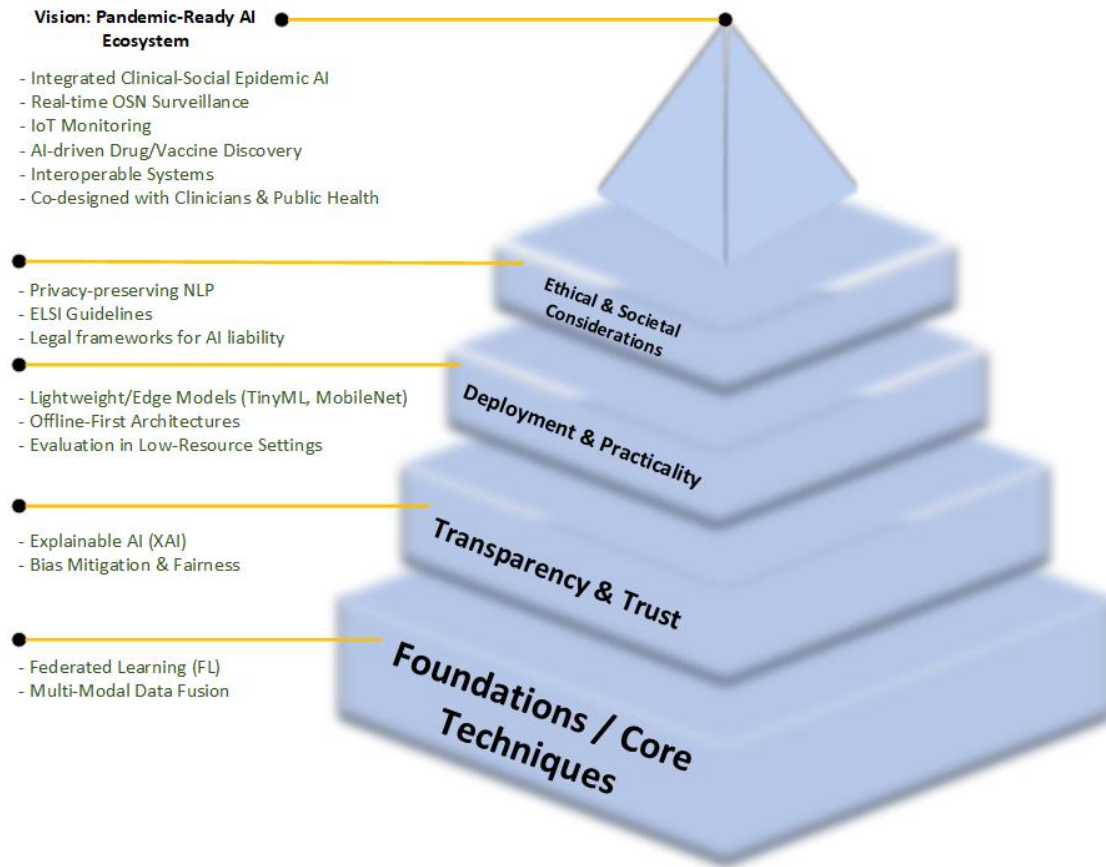


Figure_ 11. Pyramid of Pandemic-Ready AI, from foundational techniques to ethical, transparent, and integrated ecosystem vision.

Table 6. Abbreviations.

Abbreviation	Definition		
AI	Artificial Intelligence	IoT	Internet of Things
DL	Deep Learning	RT-PCR	Reverse Transcription Polymerase Chain Reaction
ML	Machine Learning	XAI	Explainable Artificial Intelligence
DNN	Deep Neural Networks	TF-IDF	Term Frequency-Inverse Document Frequency
CNN	Convolutional Neural Network	ELSI	Ethical, Legal, and Social Implications
SARS-CoV-2	Severe Respiratory Syndrome Coronavirus type 2	OSNs	Online Social Networks
ICSE-AI	Integrated Clinical-Social Epidemic AI	RL	Reinforcement Learning
LLM	Large Language Models	NLP	Natural language processing
ResNet	Residual Neural Network	VGG	Visual Geometry Group Network
CASP	Critical Appraisal Skills Programme	SHAP	SHapley Additive exPlanations

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [Arman Kavooosi Ghafi, Issa Khodadadi, Aidin Tofangdarzade, Ali Pirkhedri,]. The first draft of the manuscript was written by [Arman Kavooosi Ghafi] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Conflict of interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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Data availability

All data generated and analyzed during this study are included in this publication. No separate datasets are available, as this work is based on a review and does not involve original data collection.

Ethics approval

We are a technical engineering major, we don't have a code of ethics, our work is personal

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