Taylor & Francis
Taylor & Francis Group

Artificial intelligence (AI) in Monkeypox infection prevention

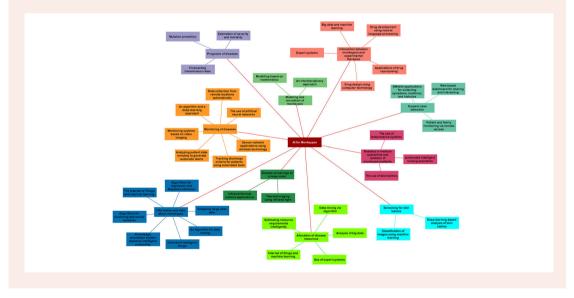Mitesh Patel[a] (iD), Malvi Surti[b] (iD) and Mohd Adnan[c] (iD)

[a]Department of Biotechnology, Parul Institute of Applied Sciences and Centre of Research for Development, Parul University, Vadodara, Gujarat, India; [b]Bapalal Vaidya Botanical Research Centre, Department of Biosciences, Veer Narmad South Gujarat University, Surat, Gujarat, India; [c]Department of Biology, College of Science, University of Hail, Hail, Saudi Arabia

Communicated by Ramaswamy H. Sarma

ABSTRACT

Monkeypox is a possible public health concern that requires appropriate attention in order to prevent the spread of the disease. Currently, artificial intelligence (AI) is making a significant impact on precision medicine, reshaping and integrating the large amount of data derived from multiomics analyses and revolutionizing the deep-learning strategies. There has been a significant progress in the use of AI to detect, screen, diagnose, and classify diseases, characterize virus genomes, assess biomarkers for prognostic and predictive purposes, and develop follow-up strategies. Hence, it is possible to use AI for the identification of disease clusters, cases monitoring, forecasting the future outbreak, determining mortality risk, diagnosing, managing, and identifying patterns for studying disease trends. AI may also be utilized to assist gene therapy and other therapies that we are not currently able to use in healthcare. It is possible to combine pharmacology and gene therapy with regenerative medicine with the help of AI. It will directly benefit the public in overcoming fear and panic of health risks. Therefore, AI can be an effective weapon to fight against Monkeypox infection, and may prove to be an invaluable future tool in improving the clinical management of patients.

Key Points: Emergence and spread of the Monkeypox virus is a new public health crisis; threatening the world. This opinion piece highlights the urgently required information for immediate delivery of solutions on controlling and monitoring the spread of Monkeypox infection through Artificial Intelligence

Introduction

There have been many outbreaks of viral diseases over the past two decades, such as Chikungunya, Ebola, Zika, Nipah, H7N9 bird flu, H1N1, SARS, MERS, and COVID-19. While COVID-19 persists, an unprecedented wave of Monkeypox cases has been reported in non-endemic regions. Presently, the virus has been spread to multiple countries outside of that endemic area, including the United Kingdom (UK), Portugal, Spain, United States (US), Canada, Sweden,

CONTACT Mitesh Patel ✉ patelmeet15@gmail.com 🖥 Department of Biotechnology, Parul Institute of Applied Sciences and Centre of Research for Development, Parul University, Vadodara, Gujarat, India; Mohd Adnan ✉ drmohdadnan@gmail.com 🖥 Department of Biology, College of Science, University of Hail, Hail, P.O. Box 2440, Saudi Arabia

Belgium, Italy, Australia, Germany, France, Netherlands, Israel, Mexico, etc. There have been around 65415 reported cases of Monkeypox disease to date (23/09/2022) (Zumla et al., 2022). As the age of artificial intelligence (AI) advances, our daily lives are being reshaped on a daily basis and it is imperative that we understand how it has evolved and what it has accomplished in order to plan for the future.

As the first human case of Monkeypox disease is reported in the Democratic Republic of the Congo, over the past 48 years, there have been various outbreaks and sporadic cases in many areas of Central and West Africa. It has been reported that most cases have occurred in remote rainforest areas of the Congo Basin, particularly in the Democratic Republic of the Congo. Also, human cases are increasingly reported in parts of Central and Western Africa (Hutin et al., 2001). A total of 11 African countries have been reported human Monkeypox cases since 1970, including Benin, Cameroon, the Central African Republic, the Democratic Republic of the Congo, Gabon, Cote d'Ivoire, Liberia, Nigeria, Sierra Leone and South Sudan (Khodakevich et al., 1988). During 1996–97, the Democratic Republic of the Congo experienced an outbreak that was characterized by a lower case fatality ratio and a higher attack rate than normal. It was found in this case that chickenpox (caused by a virus other than an orthopoxvirus, called varicella) and monkeypox were occurring concurrently. This could explain any observed changes in transmission dynamics in this case. The outbreak in Nigeria that began in 2017 has been a large one, with over 500 suspected cases and 200 confirmed cases, and a case fatality ratio of approximately 3% (Khodakevich et al., 1987). Until this day, cases continue to come to light.

Since monkeypox does not only affect countries in Africa, but the rest of the world as well, the disease is of global importance when it comes to public health. A monkeypox outbreak occurred in the US in 2003, the first monkeypox outbreak outside of Africa, and the cause was found to be contact with infected pet prairie dogs. They were housed together with Gambian pouched rats and dormice that were imported into the country from Ghana, and they were kept together (Magnus et al., 2009). During this outbreak, over 70 cases of Monkeypox were reported in the US. Monkeypox has also been reported to have been transferred from travellers from Nigeria to Israel in September 2018, to travellers from the UK in September 2018, to travellers from the US in December 2019, and to travellers from Singapore in May 2019. Multiple Monkeypox cases have been reported in several countries outside the endemic area in May 2022. Currently, there are studies being conducted to better understand the epidemiology, sources of infection, and patterns of transmission (Magnus et al., 2009).

Currently, AI is an emerging and rapidly evolving field that represents a model that can be applied to a variety of scientific fields (Hamamoto et al., 2020; Bhinder et al., 2021; Kann et al., 2021). It can be regarded as a method of learning and recognizing patterns and interactions from a sufficient number of representative models in order to improve the current approach to the decision-making process in a specific area by applying this information to the current

approach (Kann et al., 2021; Huynh et al., 2020; Nicolò et al., 2020). There are several vector-borne, sexually transmitted, healthcare-associated and infectious diseases against which AI based technologies are used to improve disease surveillance, prevention and control. The most commonly mentioned infectious disease are Influenza, Dengue, Ebola, Malaria, Zika virus, Tuberculosis, Human immunodeficiency Virus/Acquired Immunodeficiency Syndrome (HIV/AIDS), Measles, Chikungunya, Hepatitis, Cholera, Middle East Respiratory Syndrome Coronavirus (MERS-CoV), Pneumonia/Pneumococcal disease, Schistosomiasis, Yellow Fever, Chickenpox (Varicella), Polio, West Nile virus, (hand, foot and mouth disease), Streptococcal infections and Corona virus disease (COVID-2019) (Nsoesie et al., 2015; Budd et al., 2020). As a result of the AI use, there are several applications that are attracting a lot of attention and are raising hopes in the fight against Monkeypox, such as:

Monitoring and predicting

By capturing information from social media platforms, calls and news sites, it is possible that AI can be harnessed to forecast the spread of monkeypox infection and develop early warning systems. It can provide valuable information about the vulnerable regions, as well as predicting the morbidity and mortality of the disease. According to BlueDot's machine learning models, it is possible to predict both the location and outbreak occurrence of the Monkeypox infection based on the available data and the cluster of cutaneous lesions cases. Data on Monkeypox that are publicly available through HealthMap have been collected, compiled, and made readily available for the purpose of facilitating the effective tracking of its spread. In recent years, there has been an increasing emphasis on the role of AI in the detection and forecasting of outbreaks of many infectious diseases by combining multitudinal and multimodal data like COVID-19 (Santosh, 2020).

Tracing and tracking

AI enables to develop a wide range of health applications or softwares for diagnosing, tracking, and monitoring Monkeypox infections using a range of smart devices such as watches, mobile phones, and cameras (Maghded et al., 2020). For example, software like AI4COVID-19 has been developed that able to take audio recordings of coughing for two seconds which can be utilized in telemedicine (Imran et al., 2020).

Case surveillance

In clinical settings, AI techniques can be used to monitor patients and predict the course of treatment. In the intensive care unit, AI may provide critical information to assist in the allocation of resources as well as decision-making regarding any emergency services or equipment's in the course of a medical procedure based on data generated from vital statistics and clinical parameters (Rahmatizadeh et al., 2020).

Likewise, with the help of AI, it is possible to predict the chances of recovery or mortality in Monkeypox cases as well as provide daily updates, store and analyse trends, and map the course of the disease.

Recent advancements in AI for the prevention of Monkeypox

Researchers recently demonstrated that AI deep models can distinguish between different types of pox, based on digital skin images of lesions and rashes associated with pox/measles. As well as overfitting and underfitting, they observed that deep models tend to have biases. It is therefore critical to ensure a larger sample size for model training in order to achieve better classification accuracy. According to these scientists, lighter deep models, with fewer trainable parameters, can also be used for Monkeypox diagnosis via smartphones, because they have fewer trainable parameters. Monkeypox detection can also be carried out remotely using digital skin images, which will enable healthcare professionals to isolate patients and contain the spread of the disease within the community as early as possible (Islam et al., 2022).

Diagnosis

A number of recent studies have shown that AI has a lot of potential, when it comes to developing image-based diagnoses of different diseases, such as cancer detection, tumour cell identification, and the detection of COVID-19 patients. Consequently, we can use a similar application to diagnose the Monkeypox-related disease since it infects the human skin, thus allowing for a digital image to be acquired and may be used to diagnose the disease further down the road. In order to take advantage of this opportunity, Ahsan et al., (2022) (Ahsan et al., 2022) have created the first public Monkeypox image dataset by collecting images from a variety of sources (e.g. newspapers, websites) and introducing the first low-modified VGG16 model for detecting Monkeypox patients using image data. The Novaplex Monkeypox virus PCR test has also been developed by Seegene Inc. (South Korea) with the help of AI in order to detect a positive case of Monkeypox in 90 minutes. Further, by using AI, it will be possible to develop a deep learning model that can be applied to identify Monkeypox, smallpox and varicella on the basis of two-dimensional and three-dimensional features of patient symptoms. There have been a number of different models developed for the identification and localization of regions of interest from both x-ray images and chest CT scans for COVID-19, such as COVNet (COVID-19 detection neural network), COVID-ResNet and COVID MTNet (Arora et al., 2020). A further step was to construct AI-based classifiers based on 16 simple parameters from a complete blood profile for predicting the outcome of Monkeypox RT-PCR results. In resource-poor settings, this may prove to be useful in reducing the number of RT-PCR tests that needs to be performed.

Reducing the burden from medical practitioners and healthcare staff

By automating several processes, such as imparting training to practitioners, determining the best mode of treatment and care based on an analysis of clinical data using pattern recognition approaches, digitalization of patient reports, and making it easier for them to interact with patients, AI-based triage systems can assist in reducing the work burden of medical staff and healthcare workers (Iwendi et al., 2020). Using AI, it is possible to categorize patients based on symptoms severity, genetic disposition, as well as their clinical reports, so that different approaches can be adopted in order to handle the patients in the most effective way. It is also possible to utilize AI in telemedicine to eliminate the need for frequent and unnecessary hospital visits in asymptomatic cases or patients with mild symptoms by using remote monitoring and data collection. Additionally, AI based medical chatbots can also assist in consultations, reducing the need for physical crowding in hospitals as well as infection spreading, allowing critical care services to be free of the burden of inefficiency due to inefficient operations (Battineni et al., 2020). Patients in remote settings can get much needed support from chatbots like Clara and Zini developed to control COVID-19. In order to make prognostic predictions, machine learning is used to extract features from other patients' data, resulting in a sample dataset that is used as a training dataset to learn about the mortality risk of the patients (Yan et al., 2020). The prediction of the development of acute skin cutaneous lesions syndrome was also made using a similar approach. It has been demonstrated that service robots and anthropomorphic robots with AI cores can be used to perform routine tasks in hospitals such as cleaning, disinfection, monitoring and providing essential services (Zeng et al., 2020).

Prediction of protein structure

In order to predict the structure of key proteins, which are crucial for virus entry and replication, AI can help. It is expected that this will provide valuable insight that can be applied to the development of drugs within a short period of time. A model based on deep residual networks (DRN) called ResNets recently employed by the AlphaFold algorithm of Google Deep Mind for predicting the protein structures of membrane proteins, protein 3a, nsp2, nsp4, nsp6 and papain-like C-terminal domains of SARS-CoV-2, which will provide huge impetus to drug discovery programs. Using DeepTracer, which is based on a customized deep convolutional neural network, it is possible to derive the protein complex structure of Monkeypox from high-resolution cryoelectron microscopy density maps and amino acid sequences generated by the program (Pfab et al., 2021).

Therapeutic development

As of right now, there are no specific treatments available for Monkeypox virus infections that has been approved by the Food and Drug Administration (FDA). Though, there are several antiviral medications that have been developed to treat

smallpox (Tecovirimat, Cidofovir, Brincidofovir, and Vaccinia Immune Globulin Intravenous (VIGIV)) that are currently being used against Monkeypox disease. However, data on their effectiveness in treating Monkeypox infections is not available. For the prevention of smallpox and Monkeypox, the JYNNEOS vaccine has been approved during the outbreak of disease in the U.S. As an alternative to JYNNEOS, ACAM2000 is available, which has also been approved to help prevent smallpox and Monkeypox. A number of AI technologies can boost and complement traditional technologies by speeding up the lead discovery, virtual screening, and validation processes by a huge margin. This will reduce the time required in bringing a drug from bench to bed by reducing the time required for the drug discovery process. Furthermore, AI can increase the pace of drug repurposing or drug repositioning by obtaining useful data based on the molecular properties of already approved and validated drugs. This is done by screening the properties of already approved and validated drugs on a molecular level, which an expert cannot do. For example, to accelerate the progress of drug discovery program, BenevolentAI implemented machine learning methods to accelerate its research and development and found the potential drug baricitinib against COVID-19 recently (Favalli et al., 2020). Similarly, virtual screening and supervised learning can be used to identify potential drugs for treating the Monkeypox. Moreover, an integrative network-based systems, pharmacological methodology can be utilized to identify the potential drugs against Monkeypox virus based on the existing repertoire of drug molecules and drug combinations that have already been discovered so far. There are also a number of AI-driven ventures including inclProjectIDentif.AI (identifying infectious disease combination therapy with artificial intelligence) and PolypharmDB which can be utilized in identifying candidates against Monkeypox virus (Abdulla et al., 2020). Additionally, there are a number of machine learning approaches that are being used in conjunction with deep learning applications so that the discovery process can be accelerated (Moskal et al., 2020).

Vaccine development

The development of a vaccine to get protection against a pathogen has never been the subject of such an intense race by mankind before. Through the harnessing of the power of AI, the pace of discovery can be accelerated by a great deal. Currently, a possible vaccine candidates for COVID-19 has been developed via using reverse vaccinology-machine learning platform called Vaxign, which relies on supervised classification models to predict possible vaccine candidates (Ong et al., 2020). The same approach can be utilized against Monkeypox infection vaccine development.

Controlling the spread of misinformation

This pandemic has become an infodemic as a result of the avalanche of information. The use of social media platforms such as Twitter, Facebook, etc. can be used to get a better understanding of knowledge, awareness, and practices related to Monkeypox in order to devise a strategy for assembling and disseminating timely, accurate information in order to mitigate its impact. It is possible to apply machine learning techniques to determine trends and analyse sentiments and provide information, where false information originates. This information can then be used to help curtail rumours and misinformation. Furthermore, the use of AI techniques can be advantageous for presenting a clear picture of recovery rates, the accessibility and availability of healthcare, as well as identifying the gaps in the health system. With AI, clinicians are now able to get the latest information about the emerging evidence in diagnosis, treatment, range of symptoms and therapeutic outcome in this highly dynamic situation, which will not only help clinicians in real-world scenarios.

Genomics

As a result of the use of AI, we can devise a method to rapidly and accurately classify available Monkeypox genomes by applying machine learning to the genetic signatures identified in the genomes. It is possible to use artificial neural networks and ontology-based side effect prediction frameworks in order to evaluate the side effects of any type of drug or formulation that may be used for the treatment of Monkeypox.

Despite the fact that there is no silver bullet available for the cure of the disease, we must make rapid progress on all fronts in order to make progress on surveillance, monitoring, prevention and treatment at the same time. It is important that we focus on understanding the molecular mechanism of Monkeypox and other viruses circulating in animal reservoirs, as this is the second outbreak after Coronavirus in recent times. We also need to build capacity in order to prevent future outbreaks by identifying the molecular mechanisms of these viruses and increasing our preparedness by building capacity for preventing future outbreaks. This outbreak has been greatly augmented by various digital technologies and AI in response to it due to the prevailing scenario that warrants the need for immediate delivery of solutions. In the study of COVID-19 diagnosis and drug discovery, AI was found to be as accurate as or even more accurate than human experts. Similarly, AI can also be utilized to fight against Monkeypox infection. However, before AI can be used in diagnosis and other areas of medicine, we need more diverse datasets to train AI models, as well as a legal framework and ethical considerations regarding the sharing of data. In the current scenario, there are several bottlenecks that limits the potential of AI to be harnessed to its fullest potential, including the availability and sharing of clinical and epidemiological data, computational resources, scalability and ethical concerns. In the end, AI-based technologies can provide some advice and information to the user. The most important thing we can do to increase our chances of preventing epidemics is to make sure that we work together to protect ourselves, to cooperate with the government's epidemic prevention policies, and to vaccinate actively. By doing so, we will be able to defeat Monkeypox in an early stage of the disease.

Authors' contributions

Mitesh Patel was responsible for conceptualization, original draft preparation, data curation, and investigation. Malvi Surti contributed to data curation, review, and editing. Mohd Adnan contributed to conceptualization, supervision, data curation, review, and editing.

Disclosure statement

The authors have no competing interests to declare that are relevant to the content of this article.

Funding

ORCID

Mitesh Patel http://orcid.org/0000-0002-9283-2124
Malvi Surti http://orcid.org/0000-0002-7609-3026
Mohd Adnan http://orcid.org/0000-0002-7080-6822

References

Abdulla, A., Wang, B., Qian, F., Kee, T., Blasiak, A., Ong, Y. H., Hooi, L., Parekh, F., Soriano, R., Olinger, G. G., Keppo, J., Hardesty, C. L., Chow, E. K., Ho, D., & Ding, X. (2020). Project IDentif. AI: harnessing artificial intelligence to rapidly optimize combination therapy development for infectious disease intervention. *Advanced Therapeutics*, 3(7), 2000034. https://doi.org/10.1002/adtp.202000034

Ahsan, M. M., Uddin, M. R., Farjana, M., Sakib, A. N., Momin, K. A., & Luna, S. A. (2022). Image Data collection and implementation of deep learning-based model in detecting Monkeypox disease using modified VGG16. *arXiv Prepr arXiv220601862*. https://doi.org/10.48550/arXiv.2206.01862

Arora, N., Banerjee, A. K., & Narasu, M. L. (2020). The role of artificial intelligence in tackling COVID-19. 15:717–724. https://doi.org/10.2217/fvl-2020-0130

Battineni, G., Chintalapudi, N., & Amenta, F. (2020). AI chatbot design during an epidemic like the novel coronavirus. *Healthcare*, 8(2), 154. https://doi.org/10.3390/healthcare8020154

Bhinder, B., Gilvary, C., Madhukar, N. S., & Elemento, O. (2021). Artificial intelligence in cancer research and precision medicine. *Cancer Discovery*, 11(4), 900–915. https://doi.org/10.1158/2159-8290.CD-21-0090

Budd, J., Miller, B. S., & Manning, E. M. (2020). Digital technologies in the public-health response to COVID-19. 26:1183–1192. https://doi.org/10.1038/s41591-020-1011-4

Favalli, E. G., Biggioggero, M., Maioli, G., & Caporali, R. (2020). Baricitinib for COVID-19: A suitable treatment? *The Lancet. Infectious Diseases*, 20(9), 1012–1013. https://doi.org/10.1016/S1473-3099(20)30262-0

Hamamoto, R., Suvarna, K., Yamada, M., Kobayashi, K., Shinkai, N., Miyake, M., Takahashi, M., Jinnai, S., Shimoyama, R., Sakai, A., Takasawa, K., Bolatkan, A., Shozu, K., Dozen, A., Machino, H., Takahashi, S., Asada, K., Komatsu, M., Sese, J., & Kaneko, S. (2020). Application of artificial intelligence technology in oncology: Towards the establishment of precision medicine. *Cancers (Basel)*, 12(12), 3532. https://doi.org/10.3390/cancers12123532

Hutin, Y. J., Williams, R. J., Malfait, P., Pebody, R., Loparev, V. N., Ropp, S. L., Rodriguez, M., Knight, J. C., Tshioko, F. K., Khan, A. S., Szczeniowski, M. V., & Esposito, J. J. (2001). Outbreak of human monkeypox, Democratic Republic of Congo, 1996 to 1997. *Emerging Infectious Diseases*, 7(3), 434–438. https://doi.org/10.3201/eid0703.017311

Huynh, E., Hosny, A., Guthier, C., Bitterman, D. S., Petit, S. F., Haas-Kogan, D. A., Kann, B., Aerts, H. J. W. L., & Mak, R. H. (2020). Artificial intelligence in radiation oncology. *Nature Reviews. Clinical Oncology*, 17(12), 771–781. https://doi.org/10.1038/s41571-020-0417-8

Imran, A., Posokhova, I., Qureshi, H. N., Masood, U., Riaz, M. S., Ali, K., John, C. N., Hussain, M. I., & Nabeel, M. (2020). AI4COVID-19: AI enabled preliminary diagnosis for COVID-19 from cough samples via an app. *Informatics in Medicine Unlocked*, 20, 100378. https://doi.org/10.1016/j.imu.2020.100378

Islam, T., Hussain, M. A., & Chowdhury, F. U. H. (2022). Islam BMR %J bioRxiv. Can artificial intelligence detect Monkeypox from digital skin images?.

Iwendi, C., Bashir, A. K., & Peshkar, A. (2020). COVID-19 patient health prediction using boosted random forest algorithm. *Frontiers in Public Health*, 8, 357.

Kann, B. H., Hosny, A., & Aerts, H. J. W. L. (2021). Artificial intelligence for clinical oncology. *Cancer Cell*, 39(7), 916–927. https://doi.org/10.1016/j.ccell.2021.04.002

Khodakevich, L., Ježek, Z., & Messinger, D. (1988). Monkeypox virus: Ecology and public health significance. *Bulletin of the World Health Organization*, 66(6), 747–752.

Khodakevich, L., Szczeniowski, M., Jezek, Z., Marennikova, S., Nakano, J., & Messinger, D. (1987). The role of squirrels in sustaining monkeypox virus transmission. *Tropical and Geographical Medicine*, 39(2), 115–122.

Maghded, H. S., Ghafoor, K. Z., Sadiq, A. S., Curran, K., Rawat, D. B., & Rabie, K. (2020). A novel AI-enabled framework to diagnose coronavirus COVID-19 using smartphone embedded sensors: design study. In *2020 IEEE 21st International Conference on Information Reuse and Integration for Data Science (IRI)* (180–187). IEEE.

Magnus, P. v., Andersen, E. K., Petersen, K. B., & Birch-Andersen, A. (2009). A pox-like disease in cynomolgus monkeys. *Acta Pathologica Microbiologica Scandinavica*, 46(2), 156–176. https://doi.org/10.1111/j.1699-0463.1959.tb00328.x

Moskal, M., Beker, W., & Roszak, R. (2020). Suggestions for second-pass anti-COVID-19 drugs based on the Artificial Intelligence measures of molecular similarity, shape and pharmacophore distribution.

Nicolò, C., Périer, C., Prague, M., Bellera, C., MacGrogan, G., Saut, O., & Benzekry, S. (2020). Machine learning and mechanistic modeling for prediction of metastatic relapse in early-stage breast cancer. *JCO Clinical Cancer Informatics*, 4, 259–274. https://doi.org/10.1200/CCI.19.00133

Nsoesie, E. O., Kluberg, S. A., & Mekaru, S. R. (2015). New digital technologies for the surveillance of infectious diseases at mass gathering events. 21:134–140. https://doi.org/10.1016/j.cmi.2014.12.017

Ong, E., Wong, M. U., Huffman, A., & He, Y. (2020). COVID-19 coronavirus vaccine design using reverse vaccinology and machine learning. *Frontiers in Immunology*, 11, 1581.

Pfab, J., Phan, N. M., & Si, D. (2021). DeepTracer for fast de novo cryo-EM protein structure modeling and special studies on CoV-related complexes. *Proceedings of the National Academy of Sciences of the United States of America*, 118, e2017525118.

Rahmatizadeh, S., Valizadeh-Haghi, S., & Dabbagh, A. (2020). The role of artificial intelligence in management of critical COVID-19 patients. *Journal of Cellular & Molecular Anesthesia*, 5, 16–22.

Santosh, K. C. (2020). AI-driven tools for coronavirus outbreak: Need of active learning and cross-population train/test models on multitudinal/multimodal data. *Journal of Medical Systems*, 44(5), 1–5. https://doi.org/10.1007/s10916-020-01562-1

Yan, L., Zhang, H.-T., & Xiao, Y. (2020). Prediction of criticality in patients with severe Covid-19 infection using three clinical features: A machine learning-based prognostic model with clinical data in Wuhan. *MedRxiv*, 27, 2020.

Zeng, Z., Chen, P.-J., & Lew, A. A. (2020). From high-touch to high-tech: COVID-19 drives robotics adoption. *Tourism Geography*, 22(3), 724–734. https://doi.org/10.1080/14616688.2020.1762118

Zumla, A., Valdoleiros, S. R., & Haider, N. (2022). Monkeypox outbreaks outside endemic regions: Scientific and social priorities. *Lancet Infectious Diseases*, 22(7), 929–931.