SARS-CoV-2: Has artificial intelligence stood the test of time

Mir Ibrahim Sajid[1], Shaheer Ahmed[2], Usama Waqar[1], Javeria Tariq[1], Mohsin Chundrigarh[1], Samira Shabbir Balouch[3], Sajid Abaidullah[4,5]

[1]Medical College, Aga Khan University, Stadium Road, Karachi, Pakistan;
[2]Medlcal College, Islamabad Medical and Dental College, Main Murree Road, Islamabad, Pakistan;
[3]Oral and Maxillofacial Surgery, King Edward Medical University, Neela Gumbad, Lahore, Pakistan;
[4]King Edward Medical University, Neela Gumbad, Lahore, Pakistan;
[5]North Medical Ward, Mayo Hospital, Neela Gumbad, Lahore, Pakistan.

Abstract
Artificial intelligence (AI) has proven time and time again to be a game-changer innovation in every walk of life, including medicine. Introduced by Dr. Gunn in 1976 to accurately diagnose acute abdominal pain and list potential differentials, AI has since come a long way. In particular, AI has been aiding in radiological diagnoses with good sensitivity and specificity by using machine learning algorithms. With the coronavirus disease 2019 pandemic, AI has proven to be more than just a tool to facilitate healthcare workers in decision making and limiting physician-patient contact during the pandemic. It has guided governments and key policymakers in formulating and implementing laws, such as lockdowns and travel restrictions, to curb the spread of this viral disease. This has been made possible by the use of social media to map severe acute respiratory syndrome coronavirus 2 hotspots, laying the basis of the "smart lockdown" strategy that has been adopted globally. However, these benefits might be accompanied with concerns regarding privacy and unconsented surveillance, necessitating authorities to develop sincere and ethical government–public relations.
Keywords: Artificial intelligence; COVID-19; Machine learning

Introduction

In the field of medicine, artificial intelligence (AI) has contributed in terms of disease diagnosis, treatment, and prevention since the middle of the last century. The increased popularity and research of this novel computing medicine merger lead to the development of the first AI-based diagnosis application by Gunn in 1976.[1] This discovery enabled a computer to accurately diagnose acute abdominal pain and list down potential differentials. Since then, the use of algorithm-based computer softwares has gained popularity in healthcare settings. It has enabled physicians and hospitals to store a large number of robust patient records, saving time and improving the quality of patient care. AI has been incorporated in medicine in various ways to process complex information with greater efficacy than human brain.

AI techniques of processing

Artificial neural network (ANN)

ANN is the most popular technique and functions like neurons in the human brain. It is used in the diagnosis of various diseases and aids in data interpretation from sources such as electrocardiograms or electroencephalograms to diagnose myocardial infarction and epilepsy, respectively. Most importantly, it is employed in diagnostic medical imaging whereby it enhances the resolution and quality of image via deep learning. ANN can analyze data from X-rays, magnetic resonance imaging, computed tomography (CT) scans, and retinal images to help formulate diagnosis of any life-threatening visual pathology via computer visioning while saving time and increasing accuracy. In laboratory diagnostics, ANN aids in detecting fluorescent labels and identifying rare cells via ghost cytometry.

Electronic medical records (EMRs)

EMRs help record patients' medical history, laboratory investigations, and radiological imaging. In addition, they also allow risk prediction for clinically important outcomes, allowing evidence-based interventions to reduce risk of adverse events.

Medical devices and sensors

AI-based wearable devices and sensors can provide accessible medical care at fingertips. An example of this

Access this article online	
Quick Response Code:	Website: www.cmj.org
	DOI: 10.1097/CM9.0000000000002058

Correspondence to: Mir Ibrahim Sajid, Medical College, The Aga Khan University, Stadium Road, Karachi 74880, Pakistan
E-Mail: ibisajid@gmail.com

Chinese Medical Journal 2022;135(15)
Received: 09-10-2021; **Online:** 28-07-2022 **Edited by:** Peifang Wei

would be constant monitoring of heart rate or serum potassium levels by sensors in smartwatches. Data from these sensors are then processed by machine vision and output displayed on smart devices.

Fuzzy expert systems

These systems utilize fuzzy logic to process ambiguous data, aiding in diagnoses of various cancers. Furthermore, they can also estimate survival years among patients while processing tumor staging, family history, and radiological and histopathological investigations.

Robots

AI-powered robots have found their way in surgery as assistants. In addition, they can be used as care bots to provide companionship to the geriatric population who are restricted to their homes along with assisting them in household work and keeping a track of their medications.

Evolutionary computation

Techniques such as "genetic algorithms" allow processing of natural selection, based on survival of the fittest.

Moreover, this system helps in estimating the possible outcomes in critically ill patients, thereby predicting outcomes and prognosis.

Softbots

Also known as "psychotherapeutic avatars", softbots can help manage pain in children suffering from cancer and detect mental health issues among children.

AI algorithms are used in the following aspects of healthcare: (1) Diagnosis—assessing risk of disease onset or early diagnosis of disease via clinical data, EMRs, genetic testing, electrodiagnosis, and medical imaging. (2) Therapeutics—interventions such as AI-based treatment of disease, robots in surgery, and use of pharmacogenomics for delivery of drug therapy. (3) Regulation—monitoring medical care, such as tracking disease process, and handling insurance. (4) Information systems—ensuring population health by creating awareness and mass screening via devices for early detection of disease.

A summary of the use of AI in clinical settings is highlighted in Table 1.

Role of Artificial Intelligence in Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2)

Identifying cases

Due to an increasing number of SARS-CoV-2 patients, early diagnosis is critical for prompt actions on patient management, infection control, and public health control measures. Identifying cases together with rigorous contact tracing, quarantine, and isolation has been recommended to restrain the pandemic. However, this is limited by the labor-intensive testing which has the risk of exposing healthcare professionals. Furthermore, there is a delay in test results, testing techniques are very expensive, and limited kits are available to cater to the growing pandemic. Here, AI-powered radiological diagnostic modalities and screening chat-bots can be employed to solve this issue.

Radiological imaging

Several different AI-powered diagnostic radiological modalities are available. While some are limited to SARS-CoV-2, the rest are also capable of diagnosing influenza, viral pneumonia, community-acquired pneumonia, and bacterial pneumonia. These technologies employ readily available X-rays and CT scans for this purpose while ensuring sufficient accuracy [Table 2].

Diagnostic chatbots

Multiple countries are using AI-powered chatbots to screen, diagnose, and disseminate safe information among masses. In France, Clevy.io is being used for evaluation of SARS-CoV-2 risk and real-time information sharing by the government and the World Health Organization.[28] Clara, a chatbot powered by Microsoft Azure and Centers for Disease Control and Prevention is available for individuals to help them make informed decisions regarding healthcare services needed, diagnosis, or treatment.

Assisting in detection and diagnosis

Different applications and software are also being used to detect and diagnose SARS-CoV-2. Cough for Cure is a tool that provides a score to individuals regarding their likelihood of suffering from SARS-CoV-2, based on the sound of their cough. Another similar tool, Coughvid, also analyses the patient's cough and helps physicians in a more accurate triage. Researchers have also created a COVID Voice Detector capable of assigning a risk score by comparing voices to those of SARS-CoV-2 patients.[29]

These tools can provide early detection of SARS-CoV-2 and have tremendous applications in global mitigation policies.

Identifying hotspots

AI has applications in contact tracing and identification of COVID-19 hotspots. Human mobility tools can be used in the setting of poor network coverage to potentially trace infectious contacts. Similarly, Google location history may also be used to collect human mobility data of confirmed cases from places that they may have visited or stayed at, including restaurants, hotels, airports, train stations, shopping malls, among others. These contact tracing methods have been previously used for disease outbreaks, such as the Ebola outbreak in 2014, tuberculosis, severe acute respiratory syndrome in 2003, and the Middle East respiratory syndrome outbreak in the Middle Eastern Saudi Arabia Peninsula region (2012) and South Korea (2015).

Table 1: Using of artificial intelligence (AI) in medicine.

Field of medicine	Author	Year	Usage of AI
Oncology	Sotoudeh *et al*[2] Arimura *et al*[3] Jha *et al*[4] Liu *et al*[5] Xu et al[6]	2019 2018 2016 2018 2019	**Classification of cancer via tumor markers and identifying mutations:** Using AI algorithms in predicting the grade of the tumor via imaging had an accuracy of 93%. Some AI models were used to predict the survival rate in glioma and illustrated an accuracy of 90.66%. **Radiomics for precision medicine in radiation therapy:** AI-based machine learning algorithms help enhance the role of radiomics in prognosis and treatment. **Detection of metastasis:** Deep learning-based AI algorithm (lymph node assistant—LYNA) used for detection of metastatic breast cancer in sentinel lymph node had an area under the curve (AUC) of 0.99 and sensitivity of 91%.
Radiology	Pesapane *et al*[7] Topol *et al*[8]	2018 2019	**Imaging analysis:** The most common application of AI is in image processing. Normally, image analysis consumes a lot of time, making it difficult for radiologists to interpret the findings. AI algorithms accelerate the process by identifying abnormal patterns.
Cardiology	Krittanawong *et al*[9] Dilsizian *et al*[10] Johnson *et al*[11] Díaz *et al*[12] Madani *et al*[13] Krittanawong *et al*[14]	2017 2013 2018 2020 2018 2019	**Cardiac imaging for diagnosis of myocardial infarction, atrial fibrillation, and other cardiovascular diseases:** Use of computer vision for interpretation of echocardiogram via image segmentation. Convolutional neural networks (CNN) used to detect hypertrophic cardiomyopathy had an AUC of 0.93. In another study, CNN had an accuracy of 91.7% in echocardiographic interpretation.
Neurology	Lee *et al*[15] Titano *et al*[16] Arbabshirani *et al*[17]	2017 2018 2018	**Intracranial computed tomography (CT) imaging for rapid diagnosis and treatment:** Prompt diagnosis of intracranial hemorrhage was made by machine learning algorithm which analyzed brain CT in less time with an AUC of 0.846. Computer-aided surveillance of acute neurologic events in cranial imaging has the potential to triage radiology workflow, thus decreasing time to treatment and improving outcomes.
Reproductive	Topol *et al*[8] Wang *et al*[18] Lamb *et al*[19]	2019 2019 1993	**Evaluation and selection of oocytes for *in vitro* fertilization (IVF):** A feed-forward artificial neural network used for the identification of competent or incompetent oocytes had an accuracy of 91.03%. **Sperm selection and semen analysis:** Since sperm analysis has several parameters and one-third causes of male infertility are idiopathic, diagnosing male infertility can often be challenging. AI algorithms used showed an overall accuracy of 89.92% with a higher accuracy for predicting chromosomal abnormalities (95%). **Selection of embryo for IVF:** Image segmentation and classification of blastocyst allowed better analysis with an accuracy of 87.8%.
Ophthalmology	Wong *et al*[20] Topol *et al*[8] Gulshan et al[21]	2016 2019 2016	**Diagnosing eye conditions:** Several studies involving neural networks to screen for diabetic retinopathy showed that the algorithm had sensitivities ranging from 87% to 90%, 98% specificity, and 0.99 AUC.
Pediatric diseases	Liang *et al*[22]	2019	A study where retinal fundus photographs were used for diagnosis of age-related macular degeneration showed an

(*continued*)

Table 1
(continued).

Field of medicine	Author	Year	Usage of AI
			accuracy of the algorithm ranging from 88% to 92%, which was comparable to expert clinicians. **Diagnosis of pediatric diseases:** AI-based systems showed high accuracy in diagnosing multiple pediatric diseases. These included asthma (AUC 0.92), encephalitis (0.837), gastrointestinal disease (0.86s), pneumonia (0.888), respiratory disease (0.935), and sinusitis (0.932). These values were higher than junior clinicians and approximately equal to or slightly lower than experienced clinicians.
Congenital diseases	Gurovich *et al*[23]	2018	**Identifying rare genetic syndromes:** Facial analysis technologies used by expert clinicians allowed identification of phenotypes of only a few diseases. Using computer version and deep learning algorithms, a facial analysis framework (DeepGestalt) was developed which showed a high accuracy of 91%. This AI algorithm identifies over 215 different genetic diseases and has far superior efficacy than expert clinicians.
Gastroenterology	Topol *et al*[8]	2019	**Finding the presence of sessile or adenomatous polyps <5mm** Looking for polyps via colonoscopy is not only time consuming but also tough for gastroenterologists. AI used in diagnosis resulted not only in an accuracy of 94% but also provided results in only 35 s.
Dermatology	Fogel *et al*[24] Esteva et al[25] Topol *et al*[8]	2018 2017 2019	**Screening for skin cancers** Skin cancer is one of the most common malignancies worldwide, requiring accurate diagnosis and screening. Carrying out a skin exam to test for any malignancy requires experienced dermatologists who are scarce. A convoluted neural network created by Esteva and colleagues in 2017 led to: Quick screening of skin lesions; and higher sensitivity and specificity to differentiate between benign and malignant skin lesions. AI simulated experienced dermatologists with the algorithm reaching an AUC of 0.94 for skin melanoma and 0.96 for carcinoma.
Mental health	Topol *et al*[8]	2019	**Diagnosing and treating depression:** Depression is a worldwide issue with few trained psychiatrists to manage the increasing number of patients. In this situation, AI can prove to be effective by: Digital tracking of depression and mood swings via keyboard interaction, audio and facial recognition, and use of sensors. Facebook posts can help screen for depression, with the information being fed into electronic health records. Machine learning has been explored for antidepressant medications, characterizing depression, predicting suicide, and bouts of psychosis in schizophrenics.
Intensive care unit (ICU) settings	Hanson *et al*[26]	2001	**Improving the efficiency of care in ICU:** AI applications, such as bedside devices, waveform analysis, patient records in electronic format, may help improve patient outcomes in ICU because of their high efficacy.
Precision medicine	Mesko *et al*[27]	2017	Precision medicine is an approach that utilizes AI algorithms to focus on the treatment and prevention of disease on grounds of genetic and environmental factors.

Table 2: Use of artificial intelligence in identifying cases.

Author(s)	Modality	Sample size	Task	Method	Accuracy
Wang *et al*[30]	CT	1065 CT images (325 COVID-19 and 740 viral pneumonia)	Diagnose COVID-19	Inception transfer-learning	Accuracy: 79.3% Specificity: 83.0% Sensitivity: 67.0%
Chen *et al*[31]	CT	106 CT images (51 COVID-19 and 55 others)	Diagnose COVID-19 and others	UNet++	Accuracy: 92.5% Specificity: 93.6% Sensitivity: 100.0%
Jin *et al*[32]	CT	1881 CT images (496 COVID-19 and 1385 others)	Diagnose COVID-19 and others	CNN	Specificity: 95.5% Sensitivity: 94.1%
Xu *et al*[33]	CT	618 CT images (219 from 110 COVID-19 patients, 224 from 224 influenza-A viral pneumonia patients, and 175 from healthy people)	Diagnose COVID-19 and influenza-A viral pneumonia	3D deep learning	Accuracy: 86.7%
Shi *et al*[34]	CT	2685 CT images (1658 COVID 19 and 1027 community-acquired pneumonia [CAP])	Diagnose COVID-19 and CAP	iSARF	Accuracy: 87.9%
Zheng *et al*[35]	CT	542 CT images (313 COVID-19 and 229 others)	Diagnose COVID-19 and others	U-Net CNN	Specificity: 91.1% Sensitivity: 90.7%
Jin *et al*[36]	CT	1136 CT images (723 COVID-19 and 413 others)	Diagnose COVID-19 and others	UNet++ CNN	Specificity: 92.2% Sensitivity: 97.4%
Li *et al*[37]	CT	4356 chest CT exams from 3322 patients	Diagnose COVID-19 and CAP	COVNet	Accuracy: 95.0%
Song *et al*[38]	CT	275 CT images (88 COVID-19, 101 bacteria pneumonia, and 86 healthy)	Diagnose COVID-19, and bacterial pneumonia	ResNet-50	Accuracy: 86.0%
Wang *et al*[39]	X-ray	16756 CXR images	Diagnose COVID-19	COVID-Net	Accuracy: 92.4%
Narin *et al*[40]	X-ray	100 CXR images (50 COVID-19 and 50 normal)	Diagnose COVID-19	ResNet50 InceptionV3 Inception-ResNetV2	Accuracy: 98.0% Accuracy: 97.0% Accuracy: 87.0%
Zhang *et al*[41]	X-ray	1531 CXR images (100 COVID-19 and 1431 other pneumonias)	Diagnose COVID-19 and others	ResNet	Accuracy: 95.2% Specificity: 70.7% Sensitivity: 96%
Ardakani *et al*[42]	CT	612 CT images (306 COVID-19 and 306 normal)	Diagnose COVID-19	CAD	Accuracy: 91.94% Sensitivity: 93.54% Specificity: 90.32% AUC: 0.965
Zhang *et al*[43]	X-ray	5208 CXR images (2060 COVID-19 and 3148 other pneumonias)	Diagnose COVID-19 and others	CV19-Net	Sensitivity: 88% Specificity: 79% AUC: 0.96
Wehbe *et al*[44]	X-ray	2214 CXR images (1192 COVID-19 and 1022 normal)	Diagnose COVID-19	DeepCOVID-XR	Accuracy: 83% Sensitivity: 75% Specificity: 93% AUC: 0.90
Zhou *et al*[45]	CT	2814 CT images (793 COVID-19 and 2021 viral pneumonia)	Diagnose COVID-19 and viral pneumonia	Trinary scheme	Accuracy: 91.7% Sensitivity: 88.9% Specificity: 94.4% AUC: 0.95

CT: Computed tomography; COVID-19: Coronavirus disease 2019; CNN: Convolutional neural networks; CXR: Chest X-ray; AUC: Area under the curve.

The structured or unstructured data collected from AI based human mobility sources can be processed using big data analytical tools to find hotspots of SARS-CoV-2 cases and implement control measures.[46] A comprehensive summary of the use of AI in identifying hotspots during the recent SARS-CoV-2 outbreak have been shown in Table 3. Identifying hotspots of disease incidence allows public health organizations to focus on preventative, isolation and curative measures towards these specific locations, thus allowing governments to enforce smart lockdowns and open up communities in a controlled manner, minimizing the socioeconomic impact of a complete

Table 3: Using of artificial intelligence in identifying hotspot.

Authors	Year	Location	Area captured and Population	Effectiveness
Petropoulos *et al*[54]	2020	China and Austria	Not mentioned Assumption: area of the two countries	The geographical spread of the virus and individual's health are being monitored by AI-powered smartphone applications. Individuals can be notified of potential infection hotspots in real time. AI is not yet playing a significant role in the fight against COVID-19.
Dasgupta *et al*[55]	2020	India	Not mentioned Assumption: area of the entire country	Prediction through social networking data proves to be effective. Tweets with hashtags of "COVID" and "coronavirus" were used to determine hotspots in different Indian states and territories. The results were compatible with the report published by the Indian government.
		United States of America, United Kingdom, New Zealand	Not mentioned Assumption: area of the entire country	Similarly, Twitter was used with the same hashtags as above to compare the total number of tweets of each country to the total number of confirmed COVID-19 cases (till April 15, 2020). The results showed a correlation (correlation coefficient of 0.995) between the two variables.
Kreuzhuber *et al*[56]	2020	(Article in Europe), Assessing global impact	Global	Canadian health monitoring company BlueDot was able to send out a warning to its clients about the COVID-19 outbreak in China and the rest of the world as early as December 31, 2019, in contrast to WHO, which notified the public nine days later. They were also able to predict the most suspected cities and countries that COVID-19 would infect using global air ticket data. The first places affected by COVID-19 were among the top 11 listed countries by BlueDot.
Bisanzio *et al*[57]	2020	Global	Global	Results of this cohort study showed that the spatiotemporal spread of reported COVID-19 cases could be predicted at a global level by analyzing openly available geolocated Twitter social media data.
COVID Near You[58]	2020	US, Canada, Mexico	All three countries. Total No. reported on website: 1,484,109 (US) 595,911 (Canada) 6640 (Mexico)	Developed by Boston Children's Hospital and Harvard Medical School, COVID-19 Near You is a real-time health reporting website in which users can report their symptoms. It shows patterns and hotspots by locations. Undetermined effectiveness.
Lee *et al*[59]	2020	US	Not mentioned Assumption: area of US	Combines features such as providing a geo-map of countries across America using information from the US CDC, John Hopkins University, and other public sources; shows a real-time Twitter feed of COVID-19 news as well as data about hospitals and other useful information to local users.
Jana *et al*[50]	2020	US and Italy	Not mentioned Assumption: area of both countries	Experiments done on data obtained for the USA and Italy reveal high prediction accuracy with high resolution.

COVID-19: Coronavirus disease 2019; WHO: World Health Organization; CDC: Center for Disease Control.

nationwide lockdown.[47] Although it seems to prove useful in a crisis like this, a major limitation to this is a breach of privacy and potential long term misuse of data.[48]

Many organizations, universities, and governments around the globe have worked together to develop combined geographical information systems, AI, and big data-enabled analytics dashboards to track and map the dynamics of the SARS-CoV-2 pandemic.

John Brownstein, chief innovation officer at Harvard Medical School, is working with a team that is using artificial intelligence and machine learning, to analyze big data consisting of social media posts, news reports, and information supplied by doctors and official health public channels about the manifestations of the virus outside of China.[49]

Using an ensemble of convolutional long short-term memory based spatiotemporal epidemic spread model on data obtained from USA and Italy revealed high prediction accuracy with high resolution.[50] Studies predicting the incidence rate of SARS-CoV-2 using artificial neural network modeling showed that the Getis-Ord Gi* could identify the location of hotspots of disease incidence rates with a significant P value of <0.05. The employed model indicated a reasonable but not a large consistency with ground-truth on holdout samples.[51]

In Naudé's early rapid review of AI against SARS-CoV-2,[52] he concludes that AI has not yet been wholly impactful against SARS-CoV-2 and argues it is unlikely to be of much use in the present pandemic due to its current limitations. Models of dynamic neural networks used to track spatiotemporal epidemiology of previous pandemics such as the 2015 Zika virus need to be retrained using data collected from the SARS-CoV-2 pandemic. Unfortunately, there is a lack historical and unbiased data available for the AI model to be trained with. This is further accentuated by the problem with using big data such as social media to track SARS-CoV-2 activity.

Hua and Shaw[53] state that SARS-CoV-2 is an infodemic as much as it is a pandemic. The sudden rise of social media posts and Google searches of nonspecific symptoms due to widespread panic leads to "noise" on social media.[53] This noise requires filtration to discern meaningful trends.

Aiding government decision making

AI has numerous applications in informing governmental policies and decision making during the SARS-CoV-2 pandemic. Many countries have successfully mitigated their local outbreaks by employing sophisticated AI-based tools for imposing implementation of travel restrictions policies, ensuring the use of personal protective measures, quarantine enforcement, and deployment of resources.

Travel restrictions

Travel restrictions are an integral component of community mitigation measures. Early and effective implementation of these restrictions can slow down the progression of the disease spread. This puts less strain on the already limited medical resources and allows medical staff to provide adequate care to infected individuals. However, non-compliance with these restrictions poses a risk of potential exacerbation of viral spread, which needs to be addressed.

Some countries are using AI-powered identity recognition systems and geolocation services to improve public compliance. For example, a program named "Oyoon" is employed by the United Arab Emirates (UAE) Police to limit the movement of Dubai residents. The program integrates facial, voice, and license plate recognition, feeds this information through a database, and analyzes it to determine whether a traveling resident has a valid travel permit or not.[60]

AI-based behavioral analytics can also predict the time and location of potential events of non-compliance by accounting for the dynamics of human behavior, culture, and individual perceptions. This can inform the deployment of enforcement units by governments in advance.[61] Furthermore, AI can also model mobility with SARS-CoV-2 transmission dynamics, allowing policymakers to predict the speed of transmission with different levels of travel restrictions.[62]

Personal protective measures

The utilization of personal protective equipment is being enforced with the help of AI-driven tools by several governments. China has combined infrared cameras with facial recognition systems to recognize citizens not wearing masks or individuals with high body temperatures.[63] AI-powered robots are also being used in China, capable of scanning temperatures of multiple individuals simultaneously within a certain radius. These robots alert relevant authorities when individuals with fever or without masks are detected—reducing the potential risk of exposing authorities to SARS-CoV-2 while conducting temperature measurements.[63]

Similar AI-based technology has also been employed in taxis in UAE. This technology uses computer vision and machine learning algorithms to scan human faces, verify if masks are worn properly, and calculate the distance between passengers and drivers.[64]

Quarantine enforcement

The World Health Organization recommends quarantine of all diagnosed with SARS-CoV-2, and their contacts for 14 days to prevent further transmission. However, authorities are forced to allow self-quarantine at homes or hotels because of limited quarantine facilities in many countries. In these circumstances, ensuring that patients are complying with their quarantine restrictions is imperative, and AI has played a vital role in enforcing this.

Bahrain, Kuwait, and Qatar have developed AI-powered applications that use computing and geolocation services to track diagnosed and suspected cases.[60] Bahrain's application, BeAware, also allows residents to track proximity to individuals with SARS-CoV-2.[65] South Korea is using algorithms that use geolocation data, surveillance-camera footage, and credit card records to trace patients.[66] In China, a red, yellow, and green color coding is assigned to residents indicating contagion risk via a smartphone program. Moreover, Austria, Poland, China, South Korea, and Singapore are also using location-based contact tracing systems to identify possible infection routes and break the transmission lines.[66]

Resource deployment

With increasing cases, healthcare facilities can face a scarcity of resources, that is, testing kits, hospital beds, ICU beds, ventilators, and healthcare professionals. COVID-19 has different patterns of disease progression and outcomes, ranging from asymptomatic patients to those with multiorgan failures. Considering this heterogeneity and limited resources, it is important to deploy systems capable of providing early warnings for disease progression and informing which patients will benefit from what resources and when.[67]

AI-based systems can be employed to streamline healthcare operations and optimize scarce resources. They can be used to anticipate expected patient numbers, provide risk and symptom assessment, and cross-reference them with the availability of required medical staff, materials, and equipment.[60,61,68] This can allow for evidence-based decision making, allowing limited resources to be allocated as effectively as possible.[69]

Aiding physicians

Healthcare professionals have a very high workload due to a massive increase in SARS-CoV-2 patients. They are also at a higher risk of infection due to their proximity to the patients. With an already shortage of healthcare workers, protecting them and alleviating their workload should be a priority in the fight against SARS-CoV-2. Here, AI can be employed for digital healthcare delivery, limiting patient contact, disinfecting hospital premises, screening healthcare professionals, and relieving their workload. A comprehensive summary is elicited in Table 4.

Digital healthcare delivery

With the introduction of travel restrictions and social distancing measures to mitigate viral spread, telehealth modalities have shown the potential to deliver care to patients with mild diseases. AI can take this one step further—allowing automating of basic processes such as taking patient history, or powering remote consultations

Table 4: Use of Artificial Intelligence (AI) in aiding healthcare professionals.

Location	Category	Applications
United Kingdom	Doctorlink App[72]	Symptoms assessment platform; video consultations (SARS-CoV-2 and other diseases).
United States of America	WhatsApp chatbot[73]	SARS-CoV-2 information service.
	AI-powered ring[74]	Early detection of SARS-CoV-2 in healthcare professionals by tracking their heart rates, temperatures, movements, and sleep patterns.
China	UV-light-zapping germicidal robots[75]	UV light disinfection.
	Robots[76]	Cleaning; disinfecting; measuring temperature, heart rate, and oxygen saturation; delivering medicine and food; entertaining and comforting patients.
	CT scan interpreter	Interpreting CT scan images to identify SARS-CoV-2 when radiologists are unavailable.
Italy	Robot[76]	Allowing visual and acoustic patient-doctor communication; measuring blood pressure and oxygen saturation; disinfecting the premises.
Denmark	UVD Robots[75]	UV light disinfection.
Belgium	Robots[77]	Speaking 53 languages for communication; scanning QR codes; measuring temperature; determining if face masks are being worn properly.
India	Robots[78]	Delivering medicine and food; UV light disinfection; registering patients; conducting preliminary screening; directing patients to relevant departments.
Tunisia	Robots[79]	Measuring heart rate, temperature, and oxygen saturation; allowing virtual communication.
Rwanda	Robots[80]	Measuring temperature; monitoring patients; delivering medicine and food; identifying people without masks.
Multinational	Suki, Kara Voice Assistant Programs[81]	Updating medical records automatically (for SARS-CoV-2 and other consultations).

CT: Computed tomography; QR: Quick response; SARS-CoV-2: Severe acute respiratory syndrome coronavirus 2; UV: Ultraviolet.

and triage such as symptom assessment platforms.[70] These technologies allow efficient delivery of care to the population during these restrictions while putting less strain on healthcare professionals and facilities.

Screening healthcare professionals

Healthcare professionals are at a higher risk of SARS-CoV-2 infection due to their proximity to patients. Hence, it is important to periodically screen them to catch any early symptoms. For this purpose, researchers in the US are testing AI-powered programs that employ common wearables, that is, rings, to monitor vital signs including heart rate, temperature, sleep cycle changes, etc.[71] This information is fed into an algorithm capable of giving hospitals early warning about professionals who need to be isolated and provided medical treatment.

Utilizing robots in healthcare settings

AI-powered robots have been employed in healthcare settings in many countries, including Belgium, China, Denmark, India, Italy, Rwanda, Tunisia, and the United States. They can deliver food and medications, monitor crucial patient parameters, disinfect healthcare premises, and complete other routine tasks. These programs can also allow virtual communication between patients and health professionals, permitting remote diagnoses.[66] This limits patient contact and helps to alleviate the workload on healthcare professionals. Since personal protective equipment (PPE) is not required by robots, they also help to reduce the strain on the limited PPE resources.

Other AI-powered tools

Several AI-powered voice assistant programs have been developed, allowing healthcare professionals to record, autocomplete clinical notes, and update medical records in realtime. This saves crucial time and reduces the workload of health professionals.

Prospect of AI in SARS-CoV-2

As discussed, SARS-CoV-2 was a medical nightmare, with the healthcare systems stretched thin and tested to their limits. The resources were limited, and the unforeseen burden on the hospitals was evident, not just in the low-income countries, but also in the developed world. However, what perhaps made up for the scarce manpower was the use of AI. The virtual chatbots with pre-fed answering algorithms were available round the clock to help the masses; the virus tracking, and local spread helped in implementing "smart lockdowns" to minimize the impact on economy and business. Moving forward, the AI can be effectively used in tracking vaccination status, availability, and compliance. This will help ensure an equitable distribution of vaccine, both, nationally and globally.

Conclusion

AI has found its way into the healthcare system and is occupying various niches, making it more efficient and reliable than humans themselves. It has facilitated in identifying key diagnoses and in predicting patient outcomes, aiding physicians in non-biased decision making. In times of SARS-CoV-2, AI has stood the test of time in terms of preventing the spread of the virus, by identifying cases and hotspots, and thereby guiding key government officials in formulating communal policies such as travel restrictions and resource allocation. This review will serve as a gateway to future implementation of AI in the field of medicine, particularly in monitoring various diseases and exploring their potential to spread. The key to integration of AI in medicine would be a global availability, even to the low- and middle-income countries where the disease burden of communicable diseases remains high.

Conflicts of interest

None.

References

1. Gunn AA. The diagnosis of acute abdominal pain with computer analysis. J R Coll Surg Edinb 1976;21:170–172.
2. Sotoudeh H, Shafaat O, Bernstock JD, Brooks MD, Elsayed GA, Chen JA, *et al*. Artificial intelligence in the management of glioma: era of personalized medicine. Front Oncol 2019;9:768. doi: 10.3389/fonc.2019.00768.
3. Arimura H, Soufi M, Kamezawa H, Ninomiya K, Yamada M. Radiomics with artificial intelligence for precision medicine in radiation therapy. J Radiat Res 2019;60:150–157. doi: 10.1093/jrr/rry077.
4. Jha S, Topol EJ. Adapting to artificial intelligence: radiologists and pathologists as information specialists. JAMA 2016;316:2353–2354. doi: 10.1001/jama.2016.17438.
5. Liu Y, Kohlberger T, Norouzi M, Dahl GE, Smith JL, Mohtashamian A, *et al*. Artificial intelligence-based breast cancer nodal metastasis detection: insights into the black box for pathologists. Arch Pathol Lab Med 2019;143:859–868. doi: 10.5858/arpa.2018-0147-OA.
6. Xu J, Yang P, Xue S, Sharma B, Sanchez-Martin M, Wang F, *et al*. Translating cancer genomics into precision medicine with artificial intelligence: applications, challenges and future perspectives. Hum Genet 2019;138:109–124. doi: 10.1007/s00439-019-01970-5.
7. Pesapane F, Codari M, Sardanelli F. Artificial intelligence in medical imaging: threat or opportunity? Radiologists again at the forefront of innovation in medicine. Eur Radiol Exp 2018;2:35. doi: 10.1186/s41747-018-0061-6.
8. Topol EJ. High-performance medicine: the convergence of human and artificial intelligence. Nat Med 2019;25:44–56. doi: 10.1038/s41591-018-0300-7.
9. Krittanawong C. The rise of artificial intelligence and the uncertain future for physicians. Eur J Intern Med 2018;48:e13–e14. doi: 10.1016/j.ejim.2017.06.017.
10. Dilsizian SE, Siegel EL. Artificial intelligence in medicine and cardiac imaging: harnessing big data and advanced computing to provide personalized medical diagnosis and treatment. Curr Cardiol Rep 2014;16:441. doi: 10.1007/s11886-013-0441-8.
11. Johnson KW, Torres Soto J, Glicksberg BS, Shameer K, Miotto R, Ali M. Artificial intelligence in cardiology. J Am Coll Cardiol 2018;71:2668–2679. doi: 10.1016/j.jacc.2018.03.521.
12. Díaz J. Barh D. Artificial intelligence in cardiovascular medicine: applications in the diagnosis of infarction and prognosis of heart failure. Artificial Intelligence in Precision Health. London; San Diego, CA: Academic Press; 2020;313–328. doi: 10.1016/B978-0-12-817133-2.00013-6.
13. Madani A, Arnaout R, Mofrad M, Arnaout R. Fast and accurate view classification of echocardiograms using deep learning. NPJ Digit Med 2018;1:6. doi: 10.1038/s41746-017-0013-1.
14. Krittanawong C, Rogers AJ, Aydar M, Choi E, Johnson KW, Wang Z, *et al*. Integrating blockchain technology with artificial intelligence for cardiovascular medicine. Nat Rev Cardiol 2020;17:1–3. doi: 10.1038/s41569-019-0294-y.
15. Lee EJ, Kim YH, Kim N, Kang DW. Deep into the brain: artificial intelligence in stroke imaging. J Stroke 2017;19:277–285. doi: 10.5853/jos.2017.02054.

16. Titano JJ, Badgeley M, Schefflein J, Pain M, Su A, Cai M, *et al*. Automated deep-neural-network surveillance of cranial images for acute neurologic events. Nat Med 2018;24:1337–1341. doi: 10.1038/s41591-018-0147-y.
17. Arbabshirani MR, Fornwalt BK, Mongelluzzo GJ, Suever JD, Geise BD, Patel AA, *et al*. Advanced machine learning in action: identification of intracranial hemorrhage on computed tomography scans of the head with clinical workflow integration. NPJ Digit Med 2018;1:9. doi: 10.1038/s41746-017-0015-z.
18. Wang R, Pan W, Jin L, Li Y, Geng Y, Gao C, *et al*. Artificial intelligence in reproductive medicine. Reproduction 2019;158: R139–R154. doi: 10.1530/REP-18-0523.
19. Lamb DJ, Niederberger CS. Artificial intelligence in medicine and male infertility. World J Urol 1993;11:129–136. doi: 10.1007/BF00182040.
20. Wong TY, Bressler NM. Artificial intelligence with deep learning technology looks into diabetic retinopathy screening. JAMA 2016;316:2366–2367. doi: 10.1001/jama.2016.17563.
21. Gulshan V, Peng L, Coram M, Stumpe MC, Wu D, Narayanaswamy A, *et al*. Development and validation of a deep learning algorithm for detection of diabetic retinopathy in retinal fundus photographs. JAMA 2016;316:2402–2410. doi: 10.1001/jama.2016.17216.
22. Liang H, Tsui BY, Ni H, Valentim C, Baxter SL, Liu G, *et al*. Evaluation and accurate diagnoses of pediatric diseases using artificial intelligence. Nat Med 2019;25:433–438. doi: 10.1038/s41591-018-0335-9.
23. Gurovich Y, Hanani Y, Bar O, Fleischer N, Gelbman D, Basel-Salmon L, *et al*. Identifying rare genetic syndromes using deep learning. arXiv 2017. doi: 10.48550/arXiv.1801.07637.
24. Fogel AL, Kvedar JC. Artificial intelligence powers digital medicine. NPJ Digit Med 2018;1:5. doi: 10.1038/s41746-017-0012-2.
25. Esteva A, Kuprel B, Novoa RA, Ko J, Swetter SM, Blau HM, *et al*. Dermatologist-level classification of skin cancer with deep neural networks. Nature 2017;542:115–118. doi: 10.1038/nature21056.
26. Hanson CW 3rd, Marshall BE. Artificial intelligence applications in the intensive care unit. Crit Care Med 2001;29:427–435. doi: 10.1097/00003246-200102000-00038.
27. Mesko B. The role of artificial intelligence in precision medicine. Expert Rev Precis Med Drug Dev 2017;2:239–241. doi: 10.1080/23808993.2017.1380516.
28. Sivasubramanian S. How AI and machine learning are helping to fight COVID-19. Available from: https://www.weforum.org/agenda/2020/05/how-ai-and-machine-learning-are-helping-to-fight-covid-19/. [Accessed on June 29, 2020].
29. Jordan D. Artificial Intelligence and the COVID-19 Pandemic. Available from: https://fpf.org/2020/05/07/artificial-intelligence-and-the-covid-19-pandemic/. [Accessed on June 29, 2020].
30. Wang S, Kang B, Ma J, Zeng X, Xiao M, Guo J, *et al*. A deep learning algorithm using CT images to screen for corona virus disease (COVID-19). Eur Radiol 2021;31:6096–6104. doi: 10.1007/s00330-021-07715-1.
31. Chen J, Wu L, Zhang J, Zhang L, Gong D, Zhao Y, *et al*. Deep learning-based model for detecting 2019 novel coronavirus pneumonia on high-resolution computed tomography. Sci Rep 2020;10:19196. doi: 10.1038/s41598-020-76282-0.
32. Jin C, Chen W, Cao Y, Xu Z. Development and evaluation of an AI system for COVID-19. medRxiv 2020. doi: 10.1101/2020.03.20.20039834.
33. Xu X, Jiang X, Ma C, Du P, Li X, Lv S, *et al*. Deep learning system to screen coronavirus disease 2019 pneumonia. Engineering 2020;6:1122–1129. doi: 10.1016/j.eng.2020.04.010.
34. Shi F, Xia L, Shan F, Song B, Wu D, Wei Y, *et al*. Large-scale screening of COVID-19 from community acquired pneumonia using infection size-aware classification. Phys Med Biol 2021. doi: 10.1088/1361-6560/abe838.
35. Wang X, Deng X, Fu Q, Zhou Q, Feng J, Ma H, *et al*. A weakly-supervised framework for COVID-19 classification and lesion localization from chest CT. IEEE transactions on medical imaging 2020;39:2615–2625. doi: 10.1109/TMI.2020.2995965.
36. Wang B, Jin S, Yan Q, Xu H, Luo C, Wei L, *et al*. AI-assisted CT imaging analysis for COVID-19 screening: building and deploying a medical AI system. Appl Soft Comput 2021;98:106897. doi: 10.1016/j.asoc.2020.106897.
37. Li L, Qin L, Xu Z, Yin Y. Artificial intelligence distinguishes COVID-19 from community acquired pneumonia on chest CT. Radiology 2020;296:200905. doi: 10.1148/radiol.2020200905.
38. Song Y, Zheng S, Li L, Zhang X, Zhang X, Huang Z, *et al*. Deep learning enables accurate diagnosis of novel coronavirus (COVID-19) with CT images. IEEE/ACM Trans Comput Biol Bioinform 2021;18:2775–2780. doi: 10.1109/TCBB.2021.3065361.
39. Wang L, Lin ZQ, Wong A. COVID-Net: a tailored deep convolutional neural network design for detection of COVID-19 cases from chest X-ray images. Sci Rep 2020;10:19549. https://doi.org/10.1038/s41598-020-76550-z.
40. Narin A, Kaya C, Pamuk Z. Automatic detection of coronavirus disease (COVID-19) using X-ray images and deep convolutional neural networks. Pattern Anal Appl 2021;24:1207–1220. doi: 10.1007/s10044021-00984-y.
41. Zhang J, Xie Y, Pang G, Liao Z, Verjans J, Li W, *et al*. Viral Pneumonia Screening on Chest X-Rays Using Confidence-Aware Anomaly Detection. IEEE Trans Med Imaging 2021;40:879–890. doi: 10.1109/TMI.2020.3040950.
42. Abbasian Ardakani A, Acharya UR, Habibollahi S, Mohammadi A. COVIDiag: a clinical CAD system to diagnose COVID-19 pneumonia based on CT findings. Eur Radiol 2021;31:121–130. doi: 10.1007/s00330-020-07087-y.
43. Zhang R, Tie X, Qi Z, Bevins NB, Zhang C, Griner D, *et al*. Diagnosis of coronavirus disease 2019 pneumonia by using chest radiography: value of artificial intelligence. Radiology 2021;298: E88–E97. doi: 10.1148/radiol.2020202944.
44. Wehbe RM, Sheng J, Dutta S, Chai S, Dravid A, Barutcu S, *et al*. DeepCOVID-XR: an artificial intelligence algorithm to detect COVID-19 on chest radiographs trained and tested on a large U.S. clinical data set. Radiology 2021;299:E167–E176. doi: 10.1148/radiol.2020203511.
45. Zhou M, Yang D, Chen Y, Xu Y, Xu JF, Jie Z, *et al*. Deep learning for differentiating novel coronavirus pneumonia and influenza pneumonia. Ann Transl Med 2021;9:111. doi: 10.21037/atm-20-5328.
46. Agbehadji IE, Awuzie BO, Ngowi AB, Millham RC. Review of big data analytics, artificial intelligence and nature-inspired computing models towards accurate detection of COVID-19 pandemic cases and contact tracing. Int J Environ Res Public Health 2020;17:5330. doi: 10.3390/ijerph17155330.
47. Hegde A, Masthi R, Krishnappa D. Hyperlocal postcode based crowdsourced surveillance systems in the COVID-19 pandemic response. Front Public Health 2020;8:286. doi: 10.3389/fpubh.2020.00286.
48. Mozur P, Zhong R, Krolik A. In Coronavirus Fight, China Gives Citizens a Color Code, With Red Flags. Available from: https://www.nytimes.com/2020/03/01/business/china-coronavirus-surveillance.html. [Accessed on June 29, 2020].
49. Knight W. How AI Is Tracking the Coronavirus Outbreak. Available from: https://www.wired.com/story/how-ai-tracking-coronavirus-outbreak/. [Accessed on June 28, 2020].
50. Paul SK, Jana S, Bhaumik P. A multivariate spatiotemporal spread model of COVID-19 epidemic using ensemble of ConvLSTM networks. J Inst Eng India Ser B 2021;102:1137–1142. doi: 10.1007/s40031-020-00517-x.
51. Mollalo A, Rivera KM, Vahedi B. Artificial neural network modeling of novel coronavirus (COVID-19) incidence rates across the continental United States. Int J Environ Res Public Health 2020;17:4204. doi: 10.3390/ijerph17124204.
52. Naude W. Artificial intelligence against COVID-19: an early review. IZA 2020. Available from: https://www.iza.org/publications/dp/13110/artificial-intelligence-against-covid-19-an-early-review. [Accessed on June 29, 2020].
53. Hua J, Shaw R. Corona virus (COVID-19) "Infodemic" and emerging issues through a data lens: the case of China. Int J Environ Res Public Health 2020;17:2309. doi: 10.3390/ijerph17072309.
54. Petropoulos G. Artificial Intelligence in the Fight Against COVID-19. Available from: https://www.bruegel.org/2020/03/artificial-intelli gence-in-the-fight-against-covid-19/. [Accessed on June 27, 2020].
55. Dasgupta A, Bakshi A, Mukherjee S, Das K, Talukdar S, Chatterjee P, *et al*. Epidemiological challenges in pandemic coronavirus disease (COVID-19): role of artificial intelligence. Preprints 2020. doi: 10.20944/preprints202005.0234.v1.

56. Kreuzhuber K. How AI, Big Data and Machine Learning Can be Used Against the Corona Virus. Available from: https://ars.electronica.art/aeblog/en/2020/03/19/ki-corona-part1/. [Accessed on June 28, 2020].
57. Bisanzio D, Kraemer M, Bogoch II, Brewer T, Brownstein JS, Reithinger R. Use of Twitter social media activity as a proxy for human mobility to predict the spatiotemporal spread of COVID-19 at global scale. Geospat Health 2020;15. doi: 10.4081/gh.2020.882.
58. Anon. COVID Near You. Available from: https://covidnearyou.org/. [Accessed on June 28, 2020].
59. Lee T. Providing People with Coronavirus-Related Data Most Useful to Them. Available from: https://engineering.berkeley.edu/news/2020/04/providing-people-with-coronavirus-related-data-most-useful-to-them/. [Accessed on June 28, 2020].
60. Consumer News and Business Channel. Some countries in the Middle East are using artificial intelligence to fight the coronavirus pandemic. Available from: https://www.cnbc.com/2020/04/16/countries-in-the-middle-east-are-using-ai-to-fight-coronavirus.html.[Last accessed on June 28,2020].
61. Gartner. Gartner Identifies Five Areas Where AI Can Improve Decision Making for Government and Healthcare CIOs During the Coronavirus Pandemic. Available from: https://www.gartner.com/en/newsroom/press-releases/2020-05-04-gartner-identifies-five-areas-where-ai-can-improve-decision-making-during-the-coronavirus-pandemic. [Accessed on June 28, 2020].
62. Banco Bilbao Vizcaya Argentaria. How Artificial Intelligence can Help Fight COVID-19. Available from: https://www.bbva.com/en/how-artificial-intelli gence-can-help-fight-covid-19/. [Accessed on June 28, 2020].
63. Inn TL. Smart City Technologies Take on COVID-19. Available from: https://penanginstitute.org/publications/issues/smart-city-technologies-take-on-covid-19/. [Accessed on June 29, 2020].
64. Business G. Dubai's RTA Deploys AI in Taxis to Curb Virus Spread. Available from: https://gulfbusiness.com/dubais-rta-deploys-ai-in-taxis-to-curb-virus-spread/. [Accessed on June 28, 2020].
65. Institute of Public Administration. Dr. Bin Shams: The International Community Lauds the Implementation of the Application "BeAware Bahrain" and Its Utilization of Modern Technology to Stop the Spread of the Corona Virus. Available from: http://www.bipa.gov.bh/en/dr-bin-shams-the-international-community-lauds-the-implementation-of-the-application-beaware-bahrain-and-its-utilization-of-modern-technology-to-stop-the-spread-of-the-corona-virus/. [Accessed on June 28, 2020].
66. Organisation for Economic Co-operation and Development (OECD). OECD Policy Responses to Coronavirus (COVID-19): Using Artificial Intelligence to Help Combat COVID-19. Available from: https://www.oecd.org/coronavirus/policy-responses/using-artificial-intelligence-to-help-combat-covid-19-ae4c5c21/. [Accessed on June 28, 2020].
67. Times TNY. The Hardest Questions Doctors May Face: Who Will Be Saved? Who Won't? Available from: https://www.nytimes.com/2020/03/21/us/coronavirus-medical-rationing.html. [Accessed on June 28, 2020].
68. Vaishya R, Javaid M, Khan IH, Haleem A. Artificial Intelligence (AI) applications for COVID-19 pandemic. Diabetes Metab Syndr 2020;14:337–339. doi: 10.1016/j.dsx.2020.04.012.
69. Hub ID. Responding to COVID-19 with AI and Machine Learning. Available from: https://www.id-hub.com/2020/04/08/responding-to-covid-19-with-ai-and-machine-learning/. [Accessed on June 28, 2020].
70. Brice P. Putting AI to Work Against COVID-19. Available from: https://www.phgfoundation.org/blog/Putting-AI-to-work-against COVID-19. [Accessed on June 29, 2020].
71. Brodwin E. 'We're racing against the clock': Researchers Test Wearables as an Early Warning System for Covid-19. Available from: https://www.statnews.com/2020/03/26/wearables-health-workers-co ronavirus/. [Accessed on June 29, 2020].
72. Newswire P. Doctorlink Selected to Provide NHS Video Consultations and Online Triage During COVID-19. Available from: https://www.prnewswire.co.uk/news-releases/doctorlink-selected-to-provide-nhs-video-consultations-and-online-triage-during-covid-19-847342122.html. [Accessed on June 29, 2020].
73. Government U. Government launches Coronavirus Information Service on WhatsApp. Available from: https://www.gov.uk/government/news/government-launches-coronavirus-information-service-on-whatsapp. [Accessed on June 29, 2020].
74. University FA. 'With This Ring,' Scientists Hope to Predict COVID-19 in Healthcare Workers. Available from: https://www.newswise.com/coronavirus/with-this-ring-scientists-hope-to-predict-covid-19-in-healthcare-workers/?article_id=732137. [Accessed on June 29, 2020].
75. Blake R. In Coronavirus Fight, Robots Report For Disinfection Duty. Available from: https://www.forbes.com/sites/richblake1/2020/04/17/in-covid-19-fight-robots-report-for-disinfection-duty/#558ec502adab. [Accessed on June 29, 2020].
76. Zeng Z, Chen P-J, Lew A. From high-touch to high-tech: COVID-19 drives robotics adoption. Tourism Geographies 2020;22:724–734. doi: 10.1080/14616688.2020.1762118.
77. Clement CR. COVID-19 Robot Patrol Rolled Out in Belgian Hospitals. Available from: https://www.reuters.com/article/us-health-coronavirus-belgium-robots/covid-19-robot-patrol-rolled-out- in-belgian-hospitals-idUSKBN2352ES. [Accessed on June 29, 2020].
78. Nainar N. Medical Robots to the Rescue in the Battle Against Coronavirus. Available from: https://www.thehindu.com/sci-tech/tech nology/gadgets/how-medical-robots-are-helping-doctors-in-the-fight-against-coronavirus/article31271989.ece. [Accessed on June 29, 2020].
79. Agence France Presse. Robot Helps Tunisia Medics Avoid Infection from Virus Patients. Available from: https://www.thenational.ae/world/mena/robot-helps-tunisia-medics-avoid-infection-from-virus-patients-1.1013856. [Accessed on June 29, 2020].
80. Forum WE. Rwandan Medical Workers Deploy Robots to Minimise Coronavirus Risk. Available from: https://www.weforum.org/agen da/2020/06/rwandan-medical-workers-robots-coronavirus-covid19-risk/. [Accessed on June 29, 2020].
81. Jordan S. Artificial Intelligence and the COVID-19 Pandemic. Available from: https://fpf.org/2020/05/07/artificial-intelligence-and-the-covid-19-pandemic/. [Accessed on June 29, 2020].

How to cite this article: Sajid MI, Ahmed S, Waqar U, Tariq J, Chundrigarh M, Balouch SS, Abaidullah S. SARS-CoV-2: Has artificial intelligence stood the test of time. Chin Med J 2022;135:1792–1802. doi: 10.1097/CM9.0000000000002058