Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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1. Introduction

In healthcare context, it is obvious that, in the very near future, by the use of artificial intelligence (AI) systems and Internet of Things (IoT)’s wearable devices or even body implants, the whole world will give up old fashion ways of diagnosis and treatment processes of diseases. AI is so present and close to the human body already and will be even more inside, out, and around of it. AI-based services have already shown promising results regarding healthcare in different landscapes, and they may even help humanity to embrace “precision medicine” in the future [1,2]. For today, the new issues arising from the spread of coronavirus disease 2019 (COVID-19) in the world have become an important part of AI services for social good. The World Health Organization (WHO) report (April 25, 2020) highlights the following [3]:

> WHO, together with heads of state, global health leaders, private sector partners and other stakeholders launched the Access to COVID-19 Tools (ACT) Accelerator, a global collaboration to accelerate the development, production and equitable access to new COVID-19 diagnostics, therapeutics and vaccines.

> WHO has seen a dramatic increase in the number of cyber-attacks directed at its staff, and email scams targeting the public. WHO asks the public to remain vigilant against fraudulent emails and recommends using reliable sources to obtain factual information about COVID-19 and other health issues.

These highlights are just examples that represent the two different situations of today, fighting against COVID-19 at a global level. It should be kept in mind that AI-based services have the power to solve these kind of problems where they are more recognized. This is very important to find the right decisions and applications for another outbreak in the future based on the solutions obtained today.
Managing disasters via AI technology can help with epidemics in similar circular phases as disaster management: mitigation or prevention, preparing to fight, responding or fighting the epidemic, and finally recovering from the impact. While there are now, and there will be, a number of significant efforts related to all these phases by leading AI organizations of the world to fight COVID-19, the actual experience gained from this current and urgent spread will help humanity to better manage similar epidemics in the future [4].

Perhaps one of the first lessons is importance of realizing that information systems in general, and AI in particular, should be a core component of public health management systems through these phases. There are several studies that actually pointed the importance of applying new technologies like AI and how they may be supportive for healthcare in fighting against COVID-19 [5,6]. For example, such services can be used in tracking the spread of virus, monitoring patients, relieving the overload on healthcare workers, identifying high-risk groups, raising awareness about self-hygiene, etc. One study proposed the seven significant applications of AI in fighting against COVID-19 by reviewing COVID-19 and AI-related keywords. This an example that shows the efficiency of AI technologies, where giving rapid response is crucial [7].

A particular pandemic requires the design of a matching set of planning and response, but there are also some core, commonly agreed set of activities. Most of the required activities are well studied by the public health sector and international nongovernment organizations (NGOs), but what is missing is how new and emerging technologies can help in any of these phases.

AI may surpass human solutions in many domains, and managing pandemics is one of them. AI does this basically with a few strong abilities, given those parameters or definition of problem domain:

- the ability to collect data from various sources in various forms regardless of language, text, image, or video streams;
- the ability to work with multidimensional complex data;
- the ability to prioritize or optimize;
- the ability to analyze data to find patterns that can be used for classification (measure of relevance) or prediction (assertion about future); and
- the ability to disseminate solutions or information about problems to intelligently selected target groups as and when needed and according to the needs and demands of these target groups individually, segmented carefully, or totally.

Such abilities of AI mostly come from the techniques of machine learning whether it be reinforcement, supervised learning, or unsupervised learning and whether the data is verbal, textual, an image, or a video stream. Perhaps, most importantly, some solutions of AI may be served in real time. Also recognized is the power of genetic algorithms or evolutionary AI in optimization.

Despite wide range of capabilities of information technologies, AI systems are used only to a limited degree in disease prevention or public health management. This has
clearly been observed through weaknesses of the whole system while all countries are fighting with COVID-19 at present. For example, most of the issues related to delays in responding and shortage of supplies and human resources due to the lack of early planning and getting ready for timely and appropriate responses may have been avoided should there already have been use of the existing AI technologies. This idea is supported by a few recent beneficial uses of AI in the current pandemic, which is supporting all stakeholders at the country or clinical levels. In all of these, an extremely critical issue is related to the design and use of ethical and responsible AI systems that are being used at present in response to COVID-19 internationally.

The main purpose of preparation of this chapter stems from the actual observation that there is a lack of sufficient commitment to AI systems by the organizations responsible for planning for, preparing for, and responding to pandemics. In the following sections, first, fighting with epidemics using AI will be presented in appropriate phases of prevention, preparation, response, and recovery. Then current examples of how AI systems are used in fighting against COVID-19 will be presented. Next, ethical uses of such systems and the lessons learned will be discussed. In the concluding remarks, the existing gaps in fighting pandemics, which can be filled by AI systems, will be enumerated, together with a summary of broad ideas how of AI can help in fighting pandemics.

2. Phases for fighting pandemics

The suggestions to use AI can be considered for a global use, especially as a part of coordination and communication, in country use or use by the practitioners at the hospitals or clinics depending on the context.

As it will clearly be evidenced in the following sections, in many countries, critical processes where AI systems could have been used are missing. For example, the organization of social distancing and tracking the contacts of the patients within a population are often done through conventional methods or simple mobile solutions. An intelligent solution provides information and recommends actions regarding the characteristics of the spread and the potential number of cases and could match these with the locally available resources at the hospitals. Such systems can also help in understanding more about the symptoms and prognosis and reliably match them to demographics or previous illnesses. AI systems can also be very practical in determining possibilities for the virus to mutate during the pandemic and the likelihood of next waves of infections. All these findings in some part of the world could be communicated, compared, and contrasted with other regions, and predictions could be made regarding the time and size of spread to other regions. The following sections will present such specific cases and will also generalize from them to have AI systems work for improving the global public health.
As with the disasters, managing pandemics requires a set of important actions in different phases: prevention, preparation, response, and recovery [8–10]. None of them are more important than the others. The key findings of this study show how significant it would have been for the leading health organizations, governments, and responsible NGOs to have AI systems already in place to benefit more from AI during all phases of managing a pandemic and save lives. This section, as shown in Fig. 6.1, outlines typical actions in these phases and provides ideas related to how AI together with new technologies could support the management of pandemics.

### 2.1 Phase I: mitigation or prevention

This phase is characterized by activities that focus on the identification and management of risks starting with a situation analysis. COVID-19-like pandemics are observed to be increasing in the recent years. Two types of risks are important:

- spark risk, where the pandemics might originate from;
- spread risk, how quickly and widely it becomes a pandemic.

Most of the critical activities are related to early identification of these risks [11]. The risk mitigation can be seen at various levels, including individual, organizational, and environmental, as none of these could be sufficiently managed in isolation. During this phase, one opportunity to benefit from AI capabilities might be finding interesting relationships in data obtained from different sources, at different times of observing risks from various locations [12]. These interrelated activities, from training health workers, patients, and the public at large to collecting data from organizations and the environment, such as waste management and climate data [13], are all early planning activities that can be supported well with AI, and all these actions can help with preventing a spark and also transmission of the disease.
An early discovery of the source of the spark is critical, as it affects successes in all the later stages and may provide essential information on how to approach the pandemic. Knowing the location of the pandemic and combining this with location-specific data gathered on ethnicity, culture, and other relevant information may help AI systems to make predictions regarding the ways the pandemic might spread further. AI systems can also be used effectively to distinguish asymptomatic, mild, and severe cases by machine learning approaches, and these approaches can be used as analytical tools. For example, if the data gained from COVID-19 patients will be intelligently integrated by different data sources (such as clinical, biochemical, and patient genetic data) and if this data can be analyzed by machine learning algorithms, it can give reliable information to be used on different landscapes such as virus spread, faster diagnosis, developing treatment, and identifying most susceptible groups in the society [12,14], which can help in the prevention of the disease at a large scale.

For the current outbreak a Canadian company, BlueDot, using AI made warnings at the end of December about a possible spark of COVID-19 from the Wuhan area. This AI system uses natural language processing (NLP) to process thousands of articles and social media postings in numerous different languages. This was an incredible support to the whole team of health workers and organizations in the world to get alerted and be ready for a possible spread.

In summary, mitigation requires establishing plans to monitor high-risk areas of spark infections, to establish preventive control measures, to improve resistance through communication and regulations, and to carry out risk analysis periodically or for suddenly emerging ones.

2.1.1 Enter artificial intelligence for pandemic prevention

- Early discovery: Similar to BlueDot, a company called BenevolentAI searches for potential sparks using NLP reading documents related to coronavirus as well as other biological processes that might lead to pandemics.
- Monitoring systems: Prevention systems can be all set for collecting and using data in potential regions from community, schools, hospitals, and travel and traffic and from smart thermometers and infrared thermal cameras.
- Communication and sharing systems: Data collected from various sources can be intelligently analyzed and intelligently shared with relevant authorities according to their needs and at the right time.

2.2 Phase II: preparation

As observed with the current COVID-19 situation, pandemics can have a severe impact on public mortality, social relations, and the economics [15]. Being well prepared can easily lead to positive results in capacity planning both for human resources and other resources, recognition of size and the dynamics of pandemics, and required responses so as to make it an effective one. Preparation can help understand the resource constraints
in relation to operation of the health sector and other relevant sectors such as sanitation and water, which in return helps improve situation analysis and timely actions on sparks.

One of the critical areas of planning is assessment of known risks and creation of contingency plans, while preparing for actions and response. AI can be an essential part of intelligent scenario analysis, risk evaluations, and prioritization. While machine learning is powerful for data heavy analysis, evolutionary methods such as genetic algorithms can be used for optimization, sharing, and allocation of resources such as staff and supply planning and finances.

Another critical planning requires determining ways of minimization of social contacts and possible ways that the infection will spread geographically. Using disease-related and other relevant data, AI can help discover various strategies and their evaluations, and as such, it can be an inevitable tool for understanding which social strategy would lead to minimal loss of lives.

Perhaps the most difficult and significant part of planning is predetermination of communication content, timing, and channels with frontline workers, stakeholders, and the public at large. AI may be used in intelligently designing appropriate content and delivery to identified targets in a timely manner and in the way they require. One other important contribution of AI can be monitoring expected disinformation and fake news on (social) media that might lead to undesired messages being communicated, especially to the public and patients, that may cause panic or, at the very least, inappropriate decisions for self-care. Predetermined communication plans and strategies made with the help of AI naturally lead to efficient, orderly, and natural flow of information.

During COVID-19, some countries, such as Turkey, that had time to prepare themselves before the infection spread in the country are seemingly better performing, as they are benefiting from the experiences of other countries such as China and Korea. AI could be used in finding optimal organization of such information sharing among authorities and relevant organizations of various countries. While getting ready to treat the bodies of the public members, it is equally important to think of support initiative for the health workers, patients, and the public at large, who might all be experiencing various forms of psychologic pressures such as anxiety and stress, as well as being indoors due to isolation. AI systems could be significant to manage shared resources for such supportive planning globally.

In summary, preparation involves major activities for ensuring the availability of human, financial, and other resources; improving the capacity of emergency services and logistics; building communication strategies; and educating health workers and the members of the public.

2.2.1 Enter artificial intelligence for pandemic preparation

- Scenario evaluations via disease models: AI can help model the potential size and speed of the spread and test various scenarios for creating a response strategy. The size, speed, and spread of an epidemic according to various locations are key information for success.
- Epidemic intelligence: Big data and AI can be used in creating epidemic intelligence to test reactions via predictions before an outbreak. Such AI-based systems can help determine and evaluate
  - who should be tested when a large number of potential patients exists,
  - risk maps showing where to target with limited resources,
  - the data accessibility and quality,
  - the cost and time it takes for sharing data from one agency to another,
  - training for the frontline workers.
- Epidemic intelligence can help prioritize actions and determine the critical time to respond and the most effective actions by looking at genetic data, population movement, etc.
- AI can help with decisions affecting plans for efficient use of finances by determining priorities and the right form of partnerships and cooperation with the public and private organizations.

2.3 Phase III: responding to or fighting pandemics

The most critical phase of managing pandemics, perhaps after mitigation, is the time of facing the actual spread of an infectious disease. The spread of COVID-19 is almost in its fifth month, having millions of confirmed cases and thousands of mortalities globally; some AI tools are already being used, but at a very small scale, for helping with the fight [16–18]. A better preparation for the outbreak could have saved more lives by helping out with some of the most important works of all stakeholders involved [19]. Just to put it lightly, AI systems could have helped significantly preventing mask wars among various countries by better resource allocation decisions and by better and faster sharing of information and experiences across countries and leading NGOs, thus allowing more cooperation and saving lives.

Responses to pandemics require turning all plans into actions, and such responses must be in proportion to the severity, scale, and intensity, as well the changing nature, of the outbreak.

Such proportionality and dynamic response can only be achieved if relevant stakeholders are aware of all information on what is known and what is missing about a pandemic and what kind of measures are required at global and local scales. Some of the most significant actions that AI seems to be useful in times of emergencies can be listed as follows:

- Infection prevention and control
  - discovery of vaccines and antivirals,
  - management of testing the relevant members of the public,
  - management of treatments,
  - contact tracing,
  - isolations and containment measures.
Managing direct support actions
- workload of health workers and other key personnel,
- procurement and allocation of supplies,
- communication among organizations and health workers,
- communication with confirmed and potential patients.

Managing the public at large
- isolation measures;
- public safety, security, and provision of essential needs such as food and hygiene;
- social and psychologic support for the population.

All these actions support each other, interact with each other, and are relevant at various scales geographically or otherwise. This creates complex and dynamic interrelated systems that need to be well managed. Such systems generate waste amounts and forms of data that can be employed by various AI techniques to find answers to issues related to priorities, optimization, categorization, and prediction.

2.3.1 Enter artificial intelligence for fighting pandemics

- (Near) real-time disease models and epidemic intelligence: The models are the same as those in the preparation phase, but this time the system often works based on real-time data and solutions are generated fast to effectively control the infection and spread.
  - Data generated from various sources, including social media, in various forms, often as text and using NLP, are used for effective response. Such data include relevant location, weather, and demographics, especially age, previous illnesses, symptoms, and treatment responses.
  - Coordination and communication can be supported through prediction and classification using travel and traffic data, workload on clinics, need for supplies, social distancing, and data summarization and dissemination for communication to the needing parties.
  - At this stage, all factors change fast, and therefore AI systems may require to be retrained and refined with new data to fit new situations, locations, and global outbreak. Self-supervised learning methods can be really helpful.
  - Intelligent genomic sequencing can help enable the accuracy and speed in identifying virulence factors, nature of the spread, and the sources, i.e., natural, accidental, or deliberate human activities.

- Response accuracy: AI systems and reliable data and their analytics increase the speed and accuracy for precise responses rather than reactions.

- Vaccination development and drug discovery: Machine learning models can help discover and predict which existing drugs and brand-new ones could treat COVID-19 [20]. Vaccination development is a discovery process for which AI systems, especially evolutionary AI systems, with reinforcement learning could help.
There are already some organizations or companies reported to be active in drug and vaccine discovery, such as those from South Korea, Hong Kong, the United States, France, the United Kingdom, and Canada.

2.4 Phase IV: recovery

In this phase, all efforts are directed to getting back to normal as much as possible, given the impact of the pandemic and how far the whole health, social, and economic systems have been influenced. It involves support for the emotional, physiologic, social, and economic well-being of health workers and the public globally.

It should be noted that even after a perfect fight against an outbreak, there still is a chance that some new sparks might be initiated somewhere in the world by someone or some travelers might start a new spread. This is true for a known virus and a mutation of a virus. Therefore the recovery processes must include a continuing look out for such incidences at all times and with effective technologies such as AI.

Naturally there may be varying degrees of success in fighting the pandemic with its all complex structure locally and globally. AI can be used in capturing the lessons learned by evaluating what has worked or not and why to identify weaknesses and improvements required for the next possible pandemics.

Recovery from pandemics may easily lead to creating and sustaining mass care for people and restoration of all lifeline services including provision of services for social needs, mental health, and emotional health. AI systems could be used, for example, in determining safety levels of various locations, places for public access and outdoor activities in terms of scores, which can be communicated to the public, perhaps, at regular levels for them to feel good in returning to normal.

2.4.1 Enter artificial intelligence for recovery

- Experience intelligence: AI can be used in collecting all relevant data and building an advisory system to help future pandemic management based on what went wrong and what went right in different locations and contexts with respective reasons at the time of fighting pandemic.
- Impact recovery systems: AI can be used to provide an understanding of calculating losses in terms of human lives and social and economic impact with recommendations to indicate ways to recover.

As mentioned earlier, the recovery systems could be at the global, country, or local practice(s) level.

3. Present artificial intelligence efforts for fighting COVID-19

Learning from typical phases of pandemics for managing public health, in Fig. 6.2, some of the ways AI could be used in fighting the current emergency with COVID-19 are
summarized. This section, in light of the phase-based analysis done in previous sections, summarizes the actual AI systems and their applications, with pointers to some of the resources created during the present COVID-19 fight. There have been numerous attempts to make up for the delay in using AI as part of the overall management of pandemics. Each of these are aiming to aid the current fight from a different perspective by various tools. In this section, some of the key initiatives will be covered, with pointers to reviews of academic articles and AI systems developed by universities, institutes, commercial organizations, and nonprofit organizations (NPOs).

3.1 Repositories and collections

- An important repository is set by the European Commission to collect ideas about possible solutions by AI and robotics and pointers to other initiatives around the world [21].
- Data scientists at the World Health Organization (WHO) and the MILA – Quebec AI Institute are working on a “map of the landscape of artificial intelligence (AI) applications that are being built to tackle the COVID-19 pandemic” [22].
- The Allen Institute for AI, working with various research groups, prepares and disseminates an open dataset, CORD-19 (COVID-19 Open Research Dataset), of thousands of scholarly articles on COVID-19 [23].
- The University of Waterloo and the New York University have opened a CORD-19 search engine, Covidex, using NLP and information retrieval tools [24].
- Wim Naude has written an article, “Artificial Intelligence against COVID-19: An Early Review,” with good coverage of the current initiatives and issues [25].
- The Ad hoc Committee on AI (CAHAI) of the EU Council has an overview of efforts on the control of COVID-19 [26].
- The Stanford Institute for Human-Centered Artificial Intelligence (HAI) sponsored a virtual conference, “COVID-19 and AI: a Virtual Conference” [27].

3.2 Early warning systems
- NLP and machine learning is used by the Canadian company BlueDot to scan data from hundreds of different sources to detect spark and spread of the virus as well as movement patterns of the people in infected areas [28].

3.3 Intelligent diagnosis and preventing spread
- AI applications in vision are being used by Baidu, for example, with infrared cameras to detect temperatures of people in public areas.
- AI diagnosis algorithms can successfully detect infection through computed tomographic (CT) scans. Such systems are developed by Alibaba, the Renmin Hospital of Wuhan University, the Wuhan EndoAngel Medical Technology Company, and the China University of Geosciences.
- Similarly, Axial’s AI tool used by the National Health Service in the United Kingdom is able to automate the analysis of CT scan images.
- In China, (see the companies Pudu Technology and MicroMultiCopter) humans are being replaced by robots and drones for delivery and spraying disinfectants in public areas, thus minimizing the spread of infection.
- Robots are also put to service individuals to check their fever and dispense sanitizers in China.
- Other uses of robots in China are inside the hospitals delivering food and medicine to patients, disinfecting the rooms, and cooking food without any human supervision.
- Intelligent web chats (for example, the Canadian company Stallion) and robots are also being used to communicate with and treat patients remotely, thus minimizing the requirement of health workers.

3.4 Drug and vaccine discovery
- AI is also used in the intelligent discovery of treatments. For instance, AlphaFold, Google’s AI company, and DeepMind are working on structure models of proteins related to COVID-19 [29].
- TheVaxign-ML tool is proposed in the prediction of vaccine candidates for COVID-19 [30].

1Various online sources and news.
• Exscientia and Diamond Light Source in the United Kingdom and Calibr of Scripps Research in the United States are aiming to identify compounds that could lead to viable drugs for COVID-19.²

These ongoing efforts in using AI for fighting COVID-19 clearly show the significance of delays. The delay results in an unorganized feed of data—sometimes there are too much data and sometimes only too little—for the AI systems to work effectively.

4. Ethical use of artificial intelligence while fighting COVID-19

The power of AI in fighting the current COVID-19 spread is not arguable. However, all parties, especially governments and their agencies such as police force, must not cross the boundaries defined by human rights, ethics, and principles of designing and using AI responsibly. To this list, some of the influential NPOs may be included. As we have seen speed and frequencies of using AI systems at this time of emergency is increasing rapidly and in this rush the risks of ignoring ethical principles, when developing AI solutions and using them, might be increasing as well. This concern is validated even more when we think of some of the applications cited earlier that require personal scans and other health info of the members of the public. We are also aware of devices and mobile applications tracking personal data and movements of individuals. So, at this critical time, there is a risk that such practices may be in breach of privacy and may be an extended habit after the fight with COVID-19 is over. Therefore there are certain principles that cannot be relaxed if the aim is to make AI useful for the social good. AI should help create a better world and sustain better human beings with improved quality of life.

• A global coordination should lead a good AI governance for all, where the responsible NGOs, NPOs, and governments collectively work to generate objective regulations. Working with private sector, they should steer AI system producers to do their best for the benefit of the public at large. In fact, all efforts, big and small, in dealing with fighting pandemics with AI should be governed by appropriate regulations.

• As clearly known, data used by AI systems and the propositions of AI systems may contain critical bias. AI systems used for public interest should remain in favor of the public interest at all times. A recent debate was brought up on the possibility of using Africa like a laboratory in vaccine and drug testing. This racist colonialism, as well as sexism and other prejudices, should be something to keep definitely clear off.

• At all cases the data collected should be as anonymous as possible so that it cannot be traced back to any member of the public.

²Various online sources and news.
• The data collected by the present AI systems being used in emergencies should have a time-limited use and should not be extended unless, in rare cases, a consent is taken and there is an inevitable need.

• AI data should be used only for the purpose that it is collected for.

• Ethical and responsible use of AI and the collected data are especially important when there is a need for sharing data to collaborate with other units of an agency or with other organizations or when data is made open for scientific and other uses. In these cases, anonymity, noncommercial use, and transparency are extremely important.

During the present fight against COVID-19, communities and individuals are going through unusual experiences, such as isolation and social distancing, and consent to give personal data. With the unethical use of AI systems, especially after the outbreak, the already partially existing public monitoring and surveillance in some countries should not be allowed to be a part of normal life. This will add immensely having “digital autocracies” dispersed all around the world.

5. Ongoing lessons from COVID-19

The ongoing evidence coming from all around the world show clearly that there has been a significant lack of preparation by almost all the counties, despite warning coming from an AI company (BlueDot) at the end of December 2019. Here are some of the issues that we have witnessed so far and the ways AI could help in the current fight with COVID-19, especially with its intelligent, remote, and mobile health solutions:

• There is an increasing need for a global coordination of public health issues, especially by using new information technologies. All countries should aim toward the same goal rather than competing for resources as seen by examples of interstate fights for purchases and distribution of necessary supplies such as masks and ventilators.

• There are unnecessarily high pressures and workloads on health workers all around the world, and an increasing number of health workers are losing their lives because of bad planning, lack of resources, and delays in response. AI-based automated diagnostic systems also contribute to decrease contact between health workers and patients [31–33].

• One of the biggest risks that exists at the moment is a sudden increase in the number of patients at health centers, which requires an appropriate level of health workers and supporting machines and other supplies. Use of AI technologies can help in planning and prioritizing treatments at the health centers, with the appropriate allocation of supplies.
• One critical action is testing, which requires careful and precise planning, especially when there are limited resources and there are no proper technology supporting the decisions for availability of tests and for determining who should take the tests first.
• Lack of planning with technology has led countries to make selfish decisions and left some of the countries alone (i.e., Italy and Spain) with certain political and economic alliances such as the European Union. Those who have power and finances seem to be receiving supplies and help more and faster than other countries.
• Some of the issues arising from the lack of global planning forced citizens with low income or without insurance either to pay unaffordable prices or to receive no treatment in some countries (i.e., 35000 USD in the United States is reported).
• The worst affected communities from COVID-19 are those living in urban areas and those who have low income and resources. This hopefully would lead to broad ideas how we use technology, especially AI, in creating smart cities and how we can have all segments of the society benefit, especially underserved communities.
• Globalization, consumption economy, and its principles for production and distribution of commodities are all seeming to be relevant how COVID-19 is sparked and spread. This is creating positive pressures in using technology more positively, for example, to use 3D (three-dimensional) and AI systems to produce commodities near locations of consumption.

Lack of a globally organized fight against COVID-19 is expected to have a severe impact on globalization, economies, political alliances, urbanization, and social and individual lives. Hopefully this may lead to having globally agreed policies on protecting the planet and nature, public health issues and pandemics, working conditions of health workers, and health supplies. In all cases, one of the key lessons for policy makers is to use emerging technologies, such as AI, as an essential and inevitable part of fighting pandemics in all four phases from prevention to recovering from negative impacts.

6. Concluding remarks
6.1 Critical gaps in managing pandemics

For many years, professionals working in the public health sector in various organizations have been studying all four phases and relevant steps that need to be taken during the management of pandemics from clinical practice level to country level and to a global level very well [9,10]. Information technologies are being used as and when needed as a specific part of the plans and practices. In the processes of managing the pandemics, there are now commonly agreed and established processes, procedures, regulations, and guidelines produced by government agencies, NGOs, and NPOs.
However, information technologies and especially emerging new technologies, such as automation, IOT, augmented and virtual realities, and especially AI, via the support of the wireless and cloud technologies, should be made an essential part of the body of public health safety programs and implementations, and these technologies need to be integrated to the whole system without any delay. Failure to do so may result in inefficiencies and unintended consequences that may cost many lives. In addition to helping in every stage of managing pandemics, AI, for example, can help especially with what are already identified gaps in the whole system:

- Tracking the overall generated data in a more balanced manner including low-income countries and not relying only on the data coming from high-resource and high-income countries.
- Quantification and determination of the impact of a pandemic, at the time of its occurrence or after it is over, have always been estimated based on some historical data using conventional methods. The historical data may not always be available and correct, and therefore intelligent methods used with some probabilistic modeling are essential. In this way, AI may remove blind spots that may arise due to working on the past data.
- Making important analysis to help with understanding the changes in medical practices and medical advances, changes in demographics, and social patterns such as travel and daily routines.
- Tracking costs in relation to various processes involved in every phase of managing pandemics and making intelligent cost-benefit analysis.
- Estimating the overall, especially quantifiable, impact of the pandemics locally and globally and taking lessons.
- Making intelligent analysis and predicting future pandemics and their nature together with expected reasons and the spark of location.

An integrated AI system, created and coordinated by all international organizations responsible for managing pandemics, can be used by all stakeholders of this process and can be of great help in closing these gaps. There is unfortunately a lack of up-to-date guidelines for health organizations to develop applications using new technologies supporting the fight against pandemics. Similarly, the regulations steering the beneficial applications of AI and data seem to be outdated and not effectively adopted to global requirements or to those of different countries. Under these circumstances, all observed during this pandemic was numerous attempts by individual governments to distribute calls for developing quick solutions to respond to present needs.

6.2 Summary of core artificial intelligence activities for managing pandemics

AI can help identify the degree and severity of risks of infectious diseases globally, enabling responsible organizations to perform better to protect public health.
AI can be used before, during, and after a pandemic by monitoring numerous pathogens, symptoms, and syndromes by gathering and analyzing data from official sources, scientific articles, and social media in numerous languages and in numerous locations.

AI can be used with nondisease data but relevant diverse data such as existing and available travel data in all its forms; past and real-time climate and weather conditions; biological data, especially from animals and insects; and social, economic, and demographic data from countries and communities.

AI can be used in intelligent organizations for managing pandemics through optimal and precise prioritization, capacity management, resource allocation of supplies and health workers, and coordination and communication using prediction and classification.

AI can be used in health centers and laboratories for vaccine and treatment discovery; image recognition of X-rays, symptoms, and treatment match; and resource planning and scheduling, patient monitoring, and predicting potential patients.

As AI uses diverse data from various sources and also personal data from the members of the society, it should be designed and used responsibly with high concerns for security, privacy, human rights, and ethics governed by commonly agreed regulations for AI to serve the overall social good for humanity.

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