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Editorial

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COVID-19 in Iceland: the rising role of artificial intelligence in public health

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A SURGEON TRANSITIONS TO WORKING IN PUBLIC HEALTH

The first case was diagnosed on 28 February 2020, in an individual returning from a ski trip in the Alps. The first domestic transmission was confirmed about a week later. The number of cases quickly escalated, and the rise of the curve was steep[1]. In mid-March, the first restrictions on gatherings were implemented as well as the restrictions on arriving travelers. The restrictions tightened a couple of weeks later. The first death was at the end of March. A tourist in his late thirties came in extremis to the hospital and went into cardiac arrest shortly thereafter[2]. Resuscitation was attempted but was unsuccessful. He was found to be positive for COVID-19. Remarkably, no one who participated in his care or resuscitation attempt was infected, probably because he had been ill for a while and was no longer infectious. This death made the situation very real for people in Iceland. After a long career as a pediatric surgeon, at this time, I was working as a physician at the Directorate of Health in Iceland, specifically the Centre for Health Security and Communicable Disease Control, and no matter what your role at the institution had been previously, it was now all about COVID-19 [Figure 1A and B].

A Contact Tracing Team had been established by the Civil Protection Department, police, and the Centre for Health Security and Communicable Disease Control. The team is staffed mainly by nurses and police and the number of people on the team changes depending on the situation. Initially, the team focused on finding contacts of cases to quarantine those individuals. Each case is interviewed, their contacts the

Figure 1. (A) Centre for Health Security and Communicable Disease Control, Directorate of Health, Reykjavik, Iceland (6th floor); and (B) located across the street from the national landmark, Höfði, which was the location of the Reykjavík Summit meeting in 1986 between General Secretary Mikhail Gorbachev of the Soviet Union and President Ronald Reagan of the United States.

previous 1-2 days before symptoms started (or when diagnosis was made) listed, and they are contacted by the team. Soon they began "backwards contact tracing" as well, meaning tracing the source of infection. In this regard, liberal testing and genetic sequencing of all positive cases is vital. The Contact Tracing Team and police also kept surveillance of those who were supposed to be in quarantine. This surveillance has now been reenforced and especially towards those who arrive from abroad from certain high-risk areas.

THE POWER OF SMART PHONES

Backwards contact tracing was supported by genetic sequencing by DeCode Genetics. Sequencing of the virus shows mutations that happen in viruses all the time and those changes can reveal how spread distributes. All new cases in Iceland, both domestic and at the border, are sequenced, usually within 2-3 days[3]. Several clusters have thus been identified, e.g., related to certain activities or gatherings. To assist with contact tracing, the Directorate of Health also developed an app called *Rakning C-19* ("Tracing C-19") that uses GPS technology on people's phones to track their whereabouts, with their agreement. Another version of the app using Bluetooth technology to locate other phones that cases have been in close contact with is now being launched after meeting several obstacles due to privacy issues. In one respect, it will be helpful to let people know if they have been in close contact with an infected individual so they can quarantine themselves right away and get tested if needed. However, there is a risk of people getting notified by being in the proximity but not in direct contact, e.g., with a windowpane in between, which could cause unnecessary worries and difficulties. In addition, there are privacy issues and concerns about who would access that data and for what purpose. However, the privacy safeguards are very secure, and if you are notified it is not possible to know who the relevant case was. Of course, if indicated, as per regular contact tracing, individuals would be contacted by the Contact Tracing Team.

Although testing was initially focused on symptomatic individuals who fulfilled certain criteria, it was expanded early on by the public health authorities to freely test individuals with any symptoms that could be COVID-19. During the first wave, Iceland had one of the highest rates of testing per capita. During the second and third waves, when fear of any shortage of pins or reagents was found to be unnecessary, testing became even easier and now anyone can order a test online, receive a bar code by SMS (text) message, and get tested the following day. Your barcode is scanned at the testing center and used to label the specimen. The results are reported within a few hours. Negative results are reported by SMS (text) message and in the app *Rakning C-19* as well as in a message in your electronic medical record (which people access using electronic ID through their phones). Positive results are however always reported to the individual by telephone from the COVID-19-outpatient service of the University Hospital. The Contact Tracing Team then goes to work.

TELEMEDICINE

At the outset, a COVID-19-outpatient service was established at Landspitali University Hospital in Reykjavik[4]. Using telemedicine, a team of doctors and nurses calls each confirmed case at diagnosis and then every day or every couple of days onwards, how often depending on their clinical status. They are the ones to tell people their diagnosis and then follow them until discharge unless they are in the hospital. The electronic medical record is used to document the patient's progress and symptoms and categorize them by their clinical status into green, yellow, and red. The goal is to keep patients at home and avoid admission if possible. If needed, patients are brought in for evaluations, tests, intravenous fluid administration, *etc*., but only admitted if necessary. Special COVID-19 ambulances pick patients up from home and bring them back. Retired physicians and nurses, or those who had stopped working in hospital and worked in other fields, were recruited back to clinical work in a special effort by the Ministry and the Directorate of Health. Some went to work in the hospital but others in the COVID-19-outpatient service. The same effort was also done in nursing and social services to recruit more people to those disciplines. For the outpatient service, the doctors and nurses could even work from home since all that was needed was a phone and a computer.

Through the electronic medical record, staff could also consult the hospital doctors and refer patients for evaluation if needed. At the end of an interview, the patient would be color coded and a date selected for the next phone call. Red cases get a phone call by a doctor daily, yellow cases get a daily phone call by a nurse or a doctor, and green cases get a phone call every 2-3 days. Discharge is also over the phone when the criteria of 14 days since diagnosis and 7 days symptom free are met. After discharge, patients can download or print out a certificate of their diagnosis and their PCR-test results (as well as antibody tests if applicable) from the electronic medical record. The same now applies for those fully vaccinated. They can obtain their certificates online. The vaccination certificate is in Icelandic, English, and French and includes a QR code for the individual´s verification. These certificates of previous infection and vaccination can be shown at the border upon arrival to Iceland to be exempted from requirements of quarantine. In December 2020, we started accepting certificates of previous COVID-19 infection at the border as well as certificates of full vaccination. These travelers still need to take a PCR test at the border, but, if it is negative, they do not need to quarantine. However, travelers without certificates have to present a negative PCR test, undergo testing here upon arrival, and have a second test on Day 5 with a quarantine in between. This has been considered to strengthen the border measures. The certificates can be electronic or on paper, but there are many versions even from the same country, making the evaluations hard and time consuming. A standardized digital certificate with a QR code for security is much awaited and now the EU has finally announced such effort. However, exemptions from measures either at the border or domestically do have ethical implications.

The hospitals in Iceland did not become overwhelmed by the situation, although in both waves the system was close to capacity and would not have tolerated much more since the bandwidth is not much to begin with. Only two hospitals can admit COVID-19 patients in Iceland. The main hospital is the University Hospital in the capital Reykjavik and the other hospital is much smaller and located in the north in the town Akureyri. The University Hospital had time during the first wave to adapt and reorganize to be ready for patients before they arrived. ICU capacity had to be expanded since there were not enough beds to admit those expected to need them. Thus, other wards were changed into ICUs and COVID-19 wards. A group of anonymous businesspeople even gave the hospital additional ventilators (which thankfully were not needed and are now actually being donated to India). The hospitals were also protected by a visitation ban and limiting admissions as much as possible by using telemedicine for follow up and routine appointments in all disciplines. Elective procedures including surgery did suffer, and there were periods when they were postponed so as not to possibly overwhelm the ICUs. However, in a healthcare system where there are already waiting lists for many procedures, this was a concern. It still has to be evaluated whether outcomes were affected to the worse, although there is no indication so far that was the case.

A total of 29 people died in 2020 due to COVID-19 in Iceland: 10 in the first wave and 19 in the second and third waves[1]. At the end of the year, 5754 active infections had been diagnosed in our population of roughly 364,000 people. This means the death rate was 8 per 100,000 inhabitants and the observed case-fatality ratio 0.5%. Of cases diagnosed, 5% were admitted to hospital and just under 1% admitted to ICU. At year end, almost 240,000 domestic tests had been taken and around 200,000 at the border, which is among the highest testing rate in the world. In December, cases of a new variant that was first diagnosed in England were found in travelers from the UK. Currently, the domestic cases are all of the so-called Alpha variant (first identified inKent). However, the cases are few and mostly already in quarantine when diagnosed.

This new variant, Alpha (lineage B.1.1.7, received much attention in the news as it was associated with an increased spread of infections in south England before the Christmas holidays. A variant with the same concerning mutation was also found during this time in South Africa (Beta) and another from Brazil (Gamma). The ECDC and WHO cautioned about increased transmission, but further data were pending[5]. All variants are associated with signs of increased transmission, but whether they cause more severe illness, pose more risk to certain groups, or affect the protection of the vaccines is still somewhat unclear. Iceland did not put any specific restrictions on travelers from the UK or elsewhere apart from others until recently when a stay in an official quarantine facility was demanded of travelers (both residents and tourists) who arrive from certain countries where the infection rate is high or data insufficient to evaluate the situation. This requirement has since been cancelled and same measures apply to all travelers at the border. Interestingly the Alpha variant has now been replaced in the UK with a yet another new variant, Delta, first identified in India.

The news from China during the first wave about the number of sick people and 2% mortality was very concerning and that would mean thousands getting sick and hundreds dying if the same happened here. A team of scientists from the University of Iceland made a mathematical model for projection of the disease based on modeling of what happened in China and South Korea[6]. Based on the projection, the epidemic curve was traced based on different scenarios. If the worst-case scenario would happen, our hospitals could not cope. Our Chief Epidemiologist had defended his PhD at the University of Iceland a few years ago and was quick to gather this team together to assist with obtaining an objective idea of what could happen. To protect our healthcare system, measures were quickly amplified when the wave rose and, somewhat surprisingly, the case numbers fell quickly. The same statistics team continued to assist during the second and third waves but in a somewhat different manner. Still using artificial intelligence (AI) in the form of

mathematical modeling, they now used a model from Finland where different public measures could be projected, e.g., how widespread mask use is, whether schools are open or not, how many people can gather, *etc*. Using that model, you could see how the curve changed depending on the measures in place[7].

THE POTENTIAL OF AI IN FIGHTING PANDEMICS

AI will be more important in healthcare in the future as patients will likely have apps to monitor their symptoms, medications, diet, and exercise. There already are apps that help people prevent chronic lifestyle-related illnesses and help patients suffering from such diseases to better manage them, hopefully boosting their quality of life and triggering improved health outcomes. One can envision patients monitoring symptoms such as for COVID-19, the flu, and chronic conditions and hopefully preventing complications and diagnosing issues sooner.

To prevent human efforts from being overwhelmed, we need tools that can streamline the diagnosis, surveillance, and treatment of COVID-19. This need is particularly pressing in relatively resource-scarce settings, such as low- or middle-income countries. AI methods emulate the decision-making process of humans via two major approaches. The first major approach is supervised machine learning, which aims to develop a predictive algorithm using regression (linear or multiple) or classification methods (e.g., decision trees and neural networks). The other major approach is unsupervised machine learning, which allows computers to explore many unclassified data and to discover novel disease or treatment patterns[8]. A review paper on the use of AI early on in the pandemic[9] addresses four areas where AI was applied to COVID-19: diagnosis[10-12], public health[13,14], clinical decision making[15], and therapeutics[16-20]. The authors concluded that, in view of the continuing increase in the number of cases and given multiple waves of infections may occur, there is a need for effective methods to help control the COVID-19 pandemic. AI holds the potential to greatly augment existing human efforts, although they identified several limitations in the papers reviewed, including insufficient data, omission of multimodal methods of AI-based assessment, delay in realization of benefits, poor internal/external validation, inability to be used by laypersons, inability to be used in resource-poor settings, presence of ethical pitfalls, and presence of legal barriers. They also pointed out several other areas in which AI has shown significant promise and suggested four other areas for possible exploration of AI: surveillance, combination with big data, operation of other core clinical services, and management of patients with COVID-19.

We are now into 2021. Many people did not mind saying goodbye (or even good riddance) to 2020. It had not been the best of years. With vaccinations coming, we hope this year will be a bit better but are realistic that it is going to take some time[21]. Vaccinations have barely started in many places. The light at the end of the tunnel is there, but the tunnel is long and dark as WHO Director-General Tedros Ghebreyesus pointed out when discussing the coming vaccines[22]. Going forward, we will see what COVID-19 has taught us and what lessons we have learned related to the pandemic, including how we can use AI to improve healthcare - namely, diagnostics, treatments, and surveillance. The need is there, and the opportunities are many. That at least might be a positive result of all this.

Epidemics and pandemics will happen again whether it is every 10 years or every 50 years. AI will be important, e.g., in projections of epidemics. Mathematical modeling of how infections will spread taking into account certain societal measures and vaccinations will assist public health agencies and governments in their reactions. It will give the public and businesses something to go by in their planning, and there is reassurance in having an idea about what will likely happen in the future even if it is an educated guess but not a certainty. Uncertainty can lead to unrest in society and anxiety for individuals. AI will assist people in checking and following their symptoms, giving them advice and even alerting their healthcare provider if

something's wrong. AI could also keep check on medication compliance and remind people to take their medications on time, which would hopefully improve public health. Contact tracing using locations and nearby phones could be useful if privacy is not violated. AI can analyze many data in real time so we can have more information more quickly, e.g., about outcomes for certain patient populations, effects of treatments, and side effects, as well as analyzing patterns of genetic sequencing of a virus or lung imaging from patients. Similarly, for vaccinations, AI can monitor when we introduce and give new vaccines to millions of people every day. AI could also make development of new medicines and vaccines more efficient, as it could gather a huge number of data points from different sources and come up with hypotheses. Thus, we can be positive about the future and technology. The situation in a pandemic changes frequently. This article reflects the status when written and any opinions stated are the authors own.

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Authors' contributions

The author contributed solely to the article.

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