CHAPTER 7

Future of Healthcare

> *"Medicine is at a critical juncture where it is necessary to keep up with the speed of discovery in the real-world."*
>
> —Charlotte Summers

Connected healthcare and AI, when applied to healthcare, brings with it the ability to transform the lives of communities globally. People demand more today than ever before, and healthcare is expected to keep up in a golden era of innovation at the same time as a paradigm shift from healthcare volume to value—patient numbers to patient outcomes. As awareness of AI in healthcare grows, so too does public expectation that it will be used to improve day-to-day experiences.

New advances in medicine and concepts that were once the futuristic topics of science fiction are gradually becoming a reality. Gene therapies, 3-D printing of human organs, liquid biopsies, robot-assisted surgeries, and voice-enabled personal assistants are now realities that are becoming more sophisticated as time goes on. Advancements in technology are affecting not only practiced medicine but the public perceptions and attitudes toward health, lifestyle, and what it means to be healthy. Healthcare must implement innovation wisely to engage as many patients as possible. Digital health technologies evolve at a lightning pace. The impact of data science, AI, machine learning, and connected healthcare technologies is tremendous and requires an unbiased mind and willingness to engage in a continually evolving environment with as much knowledge as possible.

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Shifting from Volume to Value

Healthcare itself is transitioning from a volume- to patient-centric value. There is a shift in medicine in which pharmacology is not the first and only line of treatment; and there is a greater emphasis on the role of lifestyle as medicine for preventative and therapeutic purposes.

Traditional payment systems in healthcare are grounded in rewarding providers for the volume of patients referred and treated. Volume-based care focuses on economies of scale. Providers receive a discrete amount of money for all of the services provided to patients for a set duration of time. Value for money, patient experience, and healthcare quality are subsequently secondary considerations for evaluation. Providers are incentivized by patient volume and the cost of the overall care provided to patients. Healthcare resource and cost pressures, exasperated doctors, and incentivized clinicians have unknowingly facilitated a “see as many patients as possible” approach that has driven disease management from a medication-first, patient-second perspective. Hospitals and clinicians are incentivized to see as many patients as possible, conduct as many tests as possible, and approach disease from a medication-first perspective.

As a result, volume-based care models are typically modeled on financial metrics such as optimizing profit or minimizing cost per patient rather than health outcomes.

Volume-based care payment systems often penalize providers financially for keeping people healthy, error reduction, or complication reduction, as they are not a driving KPI. For instance, if you were to be diagnosed with type 2 diabetes, your healthcare team would typically do the following:

- Be given information on how to manage blood glucose levels per current guidance.
- Progress on a treatment regime.
- Be given information about dietary choices.

In the UK. for example, if a doctor's surgery or clinic were to enable the patient to realize type 2 diabetes remission, the surgery or clinic would fail to receive the money it would have for the drugs no longer prescribed to the patient. Personal biases can also complicate matters. In the UK, for example, doctors involved in assessing which drugs should be prescribed to NHS patients were found by The Telegraph to have received £100,000 per year from pharmaceutical companies.[116]

Volume-based care is focused on a finite amount of money for a population. With populations growing and resources stretched, the evolution toward value-based care has been expedited. Healthcare is now in a transition toward patient-based care, which is synonymous with value, rather than volume.

Tseng et al. defined the value in healthcare to be the quality of care, typically measured through healthcare outcomes.[117] A value metric also for consideration is patient experience or patient-centeredness. Patient-centeredness is an important but not necessarily dominant quality measure for value-based care. Patient-centered care utilizes a multifaceted approach, revolving around the patient, their goals, and the wider family in decisions and evaluations. There are several domains to patient-centered care, which includes patient-centeredness.

Patient-centered care is a collaborative and multifaceted approach involving delivering health and social care focused on patient experience and patient outcomes. Patient-centered care focuses on empowering patients with the knowledge and experience, skills, and confidence to manage and optimize their health. Care is compassionate, personalized, coordinated around the patient, and respectful of the patient's worldview. These goals may appear commonsense for healthcare practitioners. However, they have not always been performed as standard practice. Healthcare has typically been reductionist in its approach, addressing a sum rather than the whole and acting for patients rather than with patients.

Organizations like Buurtzorg Neighbourhood Care in the Netherlands are an exemplars of patient-centered care. The organization delivers care to 80,000 patients a year with 10,000 nurses, 21 coaches, and two managers.[118] The collaborative approach focuses on empowering patients through relationships with caregivers. Over time, patients see improvements in health status while the total external care time required is reduced. Patients and families are enabled with the skills and confidence to look after themselves.

Although two distinct philosophies, patient-centered care and value-based care are becoming synonymous. Definitions of success incorporating patient-centered outcomes, perspectives, experiences, and preferences are positively influencing quality and delivery of care.

Value-based care does not mean cheap or economy care. Indeed, care is evaluated through the quality of patient experience and outcomes; and the model reshapes how care is received by patients.

Wellness and prevention are emphasized in value-based care. Lifestyle, behavior, and environmental factors account for 90% of disease risk.[119] This has been evidenced by the growing prevalence of type 2 diabetes across the world. With growing pressure on healthcare resources, lifestyle medicine has silently refocused efforts on the role of lifestyle as medicine. Evidence demonstrates that activity, nutrition, sleep, and stress all impact physical and emotional health markers.[120] Lifestyle medicine's focus on lifestyle and behavior enables healthcare professionals to deal with reversible, non-communicable diseases such as type 2 diabetes and hypertension. Rather than treating the patient in a reductionist approach, the patient is provided with holistic, compassionate care. The prescription of lifestyle medicine is already taking place in healthcare, with digital applications prescribed to treat disease. Type 2 diabetes patients, for example, may be prescribed the Low Carb Program app from Diabetes Digital Media, demonstrated to place type 2 diabetes into remission for 1 in 4 patients.[121] Lifestyle interventions are typically safe, easy to implement, and scalable. Growing levels of chronic disease can be mitigated with a simple approach delivered in an engaging and effective setting.

Instead of reacting to events, there is a preventative, lifestyle-first approach to health in value-based care. The focus is on patient wellness, healthcare quality, and efficiency. This is where patient data, digital health, and AI hold a fountain of promise. The emphasis on efficiency ensures that the approach is scalable and effective, enabling providers to reduce healthcare costs and improve patient clinical health outcomes. Prevention of disease through quitting smoking, nutritional change, lifestyle change, activity, sleep, and identifying genetic risk factors reduces the burden on healthcare resources. Wellness is becoming incentivized. It has become the best interest of insurance companies and healthcare providers to monitor their patients' health more closely. Start-ups and digital technology companies are developing digital health tools that are disrupting the traditional doctor–patient relationship and have enabled providers to become third actors involved in facilitating sustained health. The goal of value-based care is to standardize healthcare processes through best practices and to democratize access and quality of care. Mining of data and historical evidence can determine which methods work and which don't.

Keeping people well reduces healthcare delivery costs and optimizes the use of resources. For instance, when managing a chronic condition such as type 2 diabetes, value-based care uses a collaborative and multidisciplinary approach to managing the disease to prevent diabetes-related complications. Patients engage with one healthcare team that is aware of patient progress and health status. The healthcare team may contain the patient's diabetes nurse, dietician, behavior health coach, and other professionals to support patient progress. The team would set patient-centered goals and help a patient with the following:

- Maintain blood glucose control.
- Introduce a digital community of people with type 2 diabetes for support.

- Provide health mentoring and habit maintenance support.
- Facilitate an activity program.
- Use the latest evidence base to provide nutritional guidance.
- Deal with the psychological aspects of type 2 diabetes.

Incentivization is transformed. Take a hospital setting, for instance, in which rather than being paid on how many patients could be seen, the hospital is being compensated based on the opposite. The hospital is paid based on how many patients are in positive health status and how many beds are available. The focus moves from the point of hospital admission to predicting the likelihood of future risks and anticipating them with preventative solutions. As well as face-to-face delivery, ongoing patient support can be provided digitally, for example, with health coaching, delivering an exercise program, or help with mental health concerns through apps, wearable technology, or telemedicine. AI and predictive analytics enable healthcare providers to optimize the delivery of healthcare, focusing on preventing and treating disease. Value-based care can utilize low-cost digital technologies to enhance and democratize care. The simultaneous collection of behavioral, demographic, health, and engagement data provides an opportunity for machine learning and development of novel AI, to rapidly improve, and learn from, user behavior and outcomes.

Managing healthcare operations and subsequently evaluating healthcare quality is complex. To assess a value-based care model, healthcare organizations must collect and analyze data, objectively assessing performance through the quality of care, patient health outcomes, and efficiency of cost. Providers can report and model preventative care metrics such as hospital readmission rates, error rates, disease progression, population health improvement, and engagement strategies. Healthcare quality is defined by several metrics. Patient experience and satisfaction scoring is typically the first metric of evaluation. Metrics such as time spent per patient, patient engagement, medication savings, and adherence are examples of quality that relates to productivity.

Many applications of AI in healthcare are within a hospital setting. Hospital management platforms are delivering a return on investment by enabling organizations to prepare. Systems that predict times of peak patient traffic, predict readmission times, and use real-time data to cope with the demand of real-world healthcare are seen as long-term systems of value to healthcare providers. Applications involved in improving clinical care demonstrate enormous potential. Long-term studies are required to evaluate the impact on disease management and population health.

Evidence-Based Medicine

Evidence-based medicine is underpinned by decision-making that is based on the latest, most reliable scientific evidence. As shown in Figure 7-1, it is an approach to solve a clinical problem by integrating best research and clinical evidence with real-world clinical expertise and patient values. In the case of healthcare, this is deemed to be randomized controlled trials and increasingly real-world evidence. Datafication and the IoT are contributing significantly to the evidence base. David Sackett, a pioneer of evidence-based medicine, defined the concept as "the conscientious explicit and judicious use of current best evidence in making decisions about the care of individual patients."[122]

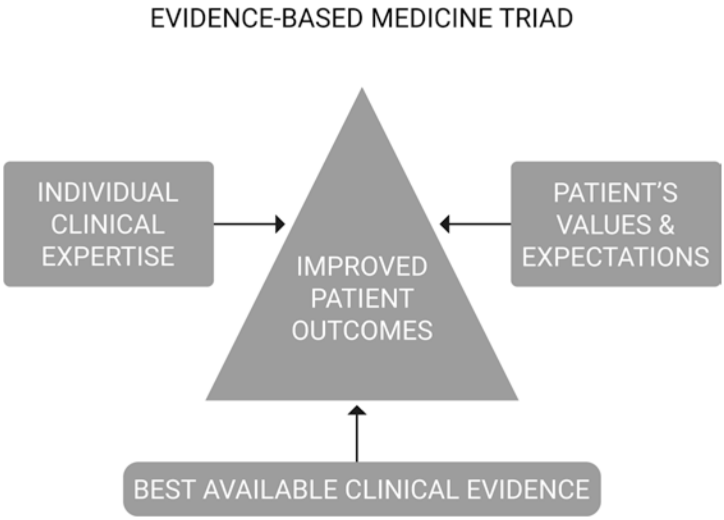

Figure 7-1. *Evidence-based medicine*

Interestingly, the traditional evidence base for pharmacology has been demonstrated to be biased, leading to questions over validity.[123] Randomized controlled trials (RCTs) are deemed as the most robust and reliable form of evidence for assessing the efficacy of a treatment. Evidence demonstrates that many factors can influence the reliability of RCTs, including methodological quality, reporting quality, and source of funding. Pharmaceutical companies fund the majority of clinical research that is undertaken on medications and face a conflict of interest. Studies have demonstrated bias in favor of industry in research funded by industry, which undermines confidence in medical knowledge.

Real-world evidence comes at a critical juncture for evidence-based medicine. Real-world evidence is disrupting traditional evidence-based hierarchies and approaches. Datafication of human experience through mobile phones, social media, digital communities, health apps, nutrition tracking, wearables, and health IoT has empowered patients to become their own evidence base and influence healthcare academia and understanding. Patients, for example, can compare the results of different hospitals, or even individual doctors, to best choose their treatment providers.

Most RCTs conducted within pharmacology are internally valid, ensuring an exact population is involved in the testing of a particular drug. For example, a trial for type 2 diabetes medication may focus on people who have type 2 diabetes only and no other comorbidities; whereas in the real world, the comorbidities of hypertension and high cholesterol are often present in people with type 2 diabetes. This approach means there is often a gap between what is reported in RCTs and what is reported by patients. This is where digital technology can help bridge the gap between pharmacological intervention and real-world patient experience. Digital communities, for example, can provide real-world evidence on medication side effects. As an example, health community Diabetes.co.uk provides medication side effect data back to pharmaceutical organizations through a mobile application in the form of analysis of patient discussion and reported side effects. The world's second-most commonly prescribed drug for diabetes, Metformin, for instance, has a side effect of diarrhea reported to affect 1 in 10 people taking the drug. Real-world evidence from Diabetes.co.uk members demonstrates this is 400% more common and reported by over 48% of people with type 2 diabetes.[124]

Real-world evidence has historically been viewed as anecdote by the medical community. However, the datafication of patient lives now means that data is directly received from devices, wearables, and sensors, ensuring that data cannot be misreported. Real-world evidence is growing at a pace that healthcare is struggling to keep up with. Digital health platforms and the aggregation of data also calls into question previous paradigms of medicine. The Low Carb Program from Diabetes Digital Media, for instance, was able to aggregate data from 100,000 people to demonstrate that a low-carbohydrate diet could be used to place type 2 diabetes into remission. Type 2 diabetes was considered, 5 years ago, to be a chronic and progressive disease. Big, real-world evidence is proving that it doesn't have to be.

It is a necessity for evidence-based medicine to keep up with the developments of real-world evidence. As David Sackett said, "half of what you learn in medical school will be out of date in 5 years of your graduation; the trouble is nobody can tell you which half. The most important thing to learn is how to learn on your own." Patients now use the Internet, themselves, and their peers as the evidence base; and ubiquity of real-world evidence and AI in healthcare means that healthcare professionals can no longer be ignorant to change in the evidence base and biased toward old paradigms.

This data is a wealth of opportunity for AI and machine learning. Healthcare can adopt a data-driven approach, utilizing a variety of data sources to improve the patient experience and reduce costs. The exploration of this data over the ensuing decades will significantly progress healthcare and facilitate precision medicine.

Personalized Medicine

Around 10% of disease risk is based on genetics.[125] Each person has a unique version of the human genome. Groups of particular patients may share common genome characteristics and thus the risk of disease. For instance, research demonstrates people of South Asian descent have a higher prevalence of type 2 diabetes compared to British Caucasians in the United Kingdom.[126] Personalized medicine, also known as stratified or precision medicine, is an approach that stratifies patients into groups and makes informed clinical decisions for the delivery of treatment and interventions based on the patients' anticipated response. Personalized medicine approaches to disease management are tailored to the patient. Patient health is managed on an individual level to achieve the most optimal state of health possible. For example, our genetic variations determine how our bodies would respond to a particular drug. One drug might not fit everyone's requirement. Two people taking the same dose of the same drug might respond differently. Using personalized medicine, a right combination of a drug and its dose can be selected for everyone. This approach to medicine is not new, and healthcare professionals have been using this approach since the time of Hippocrates. However, the hyper-personalization achievable from the use of the patient genome and its falling cost—and medical data from health records, wearable technology, and the health IoT—has roused the public interest once again. It has never before been possible to predict the risk of disease, how the human body will respond to a particular medication, or print treatments out of materials other than ink. The combination of these technologies will fuel an era of personalized care and healthcare innovation.

Predictive tools can be used to evaluate health risks and develop personalized healthcare plans to mitigate patient health risks, prevent disease, manage disease, and treat a disease precisely if it occurs. As healthcare becomes increasingly personalized for patients in both treatment and service delivery, it is critical that access is widened to ensure participation from all groups of society.

Diagnostic tests, such as blood tests, are typically used to identify appropriate treatments based on a patient's physiological analysis. The selection of optimal therapies will be increasingly personalized to the patient genome. Healthcare providers will be able to diagnose current illnesses, predict future risks of diseases, and identify predicted response to treatments and subtle traits within an instant. Genetic testing has started to make an impact in personalized medicine; DNA results are limited to being imported into services that can personalize treatment regimes, diet plans, or education to a patient. Currently, DNA test results take weeks to receive. An era of instant genetic test results will empower patients to make informed choices about treatment, services, products, medications, and outcomes.

Raising serious ethical issues, the decision to have a genetic test and the implications of its results deserves careful preparation and thought.

For providers, it provides an opportunity to fully engage in personalized, value-based care, with the quality of patient experience paramount. For patients, it can pinpoint genetic mutations that predispose a person to disease. The physical and mental consequences of such knowledge can be profound and have caused controversy among the medical establishment and general public. A natural division among all people, regarding specific issues, is to be either for or against the topic of discussion. Progress is not without moral consequence, and legislation must endure the speed at which first-time problems are occurring. People are conflicted about having a lot of information about themselves.

Vision of the Future

Within the next decade, DNA profiling of the embryo will take place from within the mother's womb, which will create an immediate profile of the person's health status and risk of disease and enable the development of health and lifestyle treatment plans from the beginning of life. Ethical concerns in fertility will move to tackle making decisions based on an embryo's genetic status. Genetic profiling will also make it quicker to detect potential concerns and alter or delete potential genetic defects or characteristics that are unfavored. Predisposition to disease will be estimated, with healthy life care plans developed for patients to follow as a daily routine. Patients will constantly be monitored, with their data fed back to update their health records and focus on optimal wellness—driven through innovation in wearable technology, innovation in medicine, healthcare delivery, the IoT, and smart homes, smart cities, and smart communities.

Patient data aggregation will facilitate the understanding of baseline health and enable healthy people to be algorithmically visualized. Data monitoring and predictive analytics will instantly alert health professionals and patients should there be a deviation to the norm—alerting users to poor health, possible illness, or nudging the user over an unhealthy lifestyle. One will be able to download a clinically validated app that would be able to detect, diagnose, and treat many diseases before attending a physical doctor's surgery. Sensors will become far less invasive—chips under the skin and smart tattoos that keep constant connectivity.

Visiting the doctor's practice will be very different. Your digital personal assistant, perhaps Siri or Alexa, may suggest you see the doctor based on your voice sounding ill, or at least different. Social media platforms, health communities, and phones will alert you to mental health problems based on what you type. No matter whether it's a hospital in Malibu or Manchester, your health record will be accessible and available on your phone and validated through a distributed ledger such as Blockchain, to which healthcare providers would continue to add to over time.

Advancements in robotics, automation, and digital health enable healthcare professionals to focus their time where needed most: with patients. Using a combination of data collected from the patient's everyday life, phone, wearables, health sensors, connected clothing—and combining that with clinical tests, scans, and check-ups—will allow much-improved analysis and monitoring and focus on health optimization. This is especially effective against non-communicable, chronic diseases like type 2 diabetes and tracking the progression of progressive conditions such as dementia. Both health providers and bill payers will incentivize patients to track symptoms and health markers to aid the treatment pathway.

Potential health concerns identified from patient data would trigger an alert to the patient's doctor for validation by a human after initial AI investigation and prioritization. As a patient, treatment will be personalized, based on health records, genetic analysis, and AI analysis of patient data. Medicines will also include 3-D printed treatments and digital interventions delivered through mobile apps. Digital interventions, measured by engagement, and health outcomes, will be hyper-personalized, based on demographics, behavior, health, goals, and preferences. Discreet wireless sensors will allow instant notifications of change, while algorithms and AI models will be used to diagnose disease and treat patients. Earlier diagnosis of health issues will become more common through constant monitoring before they become more serious.

Care will be delivered through a hybrid of digital and face-to-face engagement. Virtual and augmented immersive experiences will reinforce and maintain behavior change. Drones will deliver your medication to wherever you are unless your autonomous vehicle takes you there first. You will be instantly alerted when data sources report an adverse effect of your medication, and you will instantly be offered a best-suited, tailored alternative. A variety of integrated healthcare disciplines will be involved in patient treatment to ensure a holistic and human approach to healthcare. Innovations will allow doctors, nurses, and wider healthcare professionals to be freed up to do the more human parts of the job. Robotic AI will be used to carry out more physical tasks such as moving patients around, creating sterile environments, performing blood tests, radiology assessments, and so on.

Patient concerns will be dealt in, in real time. Should a patient be showing symptoms of atrial fibrillation, for example, a doctor may record a patient's heartbeat on their tablet and upload it to a system that confirms or denies the doctor's concerns. If irregularities are spotted, the video is instantly sent to a cardiologist who can provide a diagnosis and begin a personalized treatment plan for the patient. Appointments and follow-ups will take hours or days rather than weeks or months. A network of connected care means several experts can look at a patient's concerns simultaneously and give second opinions.

Precision medicine is another emerging approach, which refers to modifying a medical treatment considering individual variability. For this measure, three additional data sets are added to existing traditional patient medical records: data about the patient's environmental exposures, their lifestyle, and their genomic data.[127] This information can assist the doctors in identifying which approaches, treatments, and preventions will be effective for which patients.

Connected Medicine

Wearables and the IoT hold the key to connected medicine. Data captured by sensors in these contraptions are playing an increasingly powerful role in healthcare, facilitating the development of patient-centric healthcare systems. Many factors are accelerating the acceptance of wearable healthcare solutions, particularly their use in clinical trials and academic studies to monitor patient health and lifestyle factors. For example, studies can record participants' health vitals using an Android Watch, Apple Watch, Garmin, Fitbit, or another smartwatch device. Participants use apps to record their lifestyle habits, nutrition, activity, and medication adherence and to monitor medication side effects among others. Wearables and patient data are beginning to be used by insurance companies to incentivize wellness. Insurance companies have historically targeted such insurance products toward digital-savvy buyers, offering the latest gadgets to incentivize health improvements. However, incentivized insurance products will become commonplace for wider populations, proving particularly effective in the combat against non-communicable diseases. The delivery of connected, digital healthcare opens an opportunity to monitor, manage, and reverse disease, broadening the risk portfolio and creating a longer-living, reduced morbidity population.

As sensors become faster, smaller, and more capable, patient health records profiles will eventually comprise of detailed sleep analyses, details of continuous blood glucose monitoring, heart rate, blood pressure, and approximate calorie burn. A smartwatch will combine a variety of diagnostic tools, able to monitor blood pressure, heart rate variability, blood glucose, ketones, and more. Health sensors will become embeddable, biodegradable, and constantly connected, playing critical roles in such tasks as patient care. It is worth noting that evidence demonstrates fitness trackers have a limited engagement lifetime and do not improve patient weight loss.

Table 7-1 briefs some examples of connected medicine devices, explaining what device can be used where and why it can be useful. For example, immersive technology devices can be worn on the head for education purposes. Some of the wearables and embedded sensors include the following:

- Stress bands

  Stress tracking and calming of the mind are two key markets for wearables. Wearables currently monitor breathing and heart rate, detecting signs of tension to improve breathing and the ability to reach a calmer state of mind. Fitness trackers offer mindfulness functions, and there are headbands that deliver waveforms to the brain.

- UV sensor

  Northwestern University has developed UV sensors that precisely monitor a person's UV light exposure. The wearable sensors, which are small enough to fit on a human fingernail, are wafer-thin. As a known and potent carcinogen, this has the potential to reduce overexposure to UV, complications such as heatstroke, and melanoma.[128]

- Smart tattoos

  Smart tattoos place the sensor in the skin with significant strides made by researchers at MIT and Harvard.[129] Smart tattoo ink reacts with the biochemical composition of the interstitial fluid to indicate the status. Developments will allow for tattoos to degrade, lasting for as long as required and even only displaying in particular lights. For instance, high blood glucose could turn a blood glucose smart tattoo red, whereas low blood glucose may turn the tattoo blue.

- Smart medication

  There are many directions to which medication is being made smart. Smart medication can tell a patient and their respective healthcare team as to the amount of medicine consumed, the time it was taken, and provide timely reminders if it looks like it may be missed. Today, Bluetooth-connected bottle caps and pill packets provide reminders to patients to encourage medication adherence. Bluetooth insulin pens and pen caps that log the time, amount, and kind of insulin injected typically push data from the device to cloud, with users engaging in a digital app interface to query their data. Smart asthma inhalers, for instance, can identify an oncoming attack before the wearer recognizes the symptoms.

- Smart insulin

  A form of smart medicine, smart insulin is next-generation insulin that responds automatically to changing blood glucose levels. The lower or higher blood sugar levels are, less or more insulin is released, respectively. In 2015, University of North Carolina researchers reported that their

> smart insulin patch, which rests on the outside of the body, will use a system of micro-needles to automatically detect high blood glucose levels and administer insulin through live beta cells appropriately. Because the beta cells are kept within the patch on the outside of the body, there is zero danger of them being rejected by the immune systems of people with type 1 diabetes.[130]

Patients immediately turn to Dr. Google at the first sign or symptom of potential illness. Patients are best placed to understand what is happening to their body, now visiting the doctor more prepared than ever. More informed, more aware, and more health-conscious patients now attend appointments, with their engagement used to personalize their healthcare plans. However, this also causes varying degrees of mental anguish and hypochondria. Patients must not forget that qualified healthcare professionals provide a much more complete assessment and explanation of health, particularly if up-to-date with the evidence base. This is perhaps a contributing factor for why the medical profession has not always welcomed a patient-centric approach. A 2018 Diabetes.co.uk survey reported 87% of patients had a better relationship with their healthcare professionals as the result of using the platform, with 75% reporting a better understanding of their condition. When this survey was conducted in 2015, the same number reported a better understanding of their condition, but only 20% of patients reported improved relationships with their healthcare team.[131]

Table 7-1. Applications of wearable technology

What?	Where?	Why?
Immersive technology	Head	Education
Military apparel		Behavior change
Helmets		Intelligence to intelligence
Mixed reality		communication
Smart contact lenses	Eyes	Blood glucose levels
Trackers		
Hearing aids	Ears	Sound
Headphones		
Trackers		
Odor detection	Nose	Smell
Smart tattoos	Arms/Wrist	Blood glucose
Trackers		Blood pressure
Patches		Oxygen saturation
Implantables		Ketone levels
Smartwatch		Education
Trackers		Rehabilitation
Clothing	Body	Rehabilitation
Chest straps		
Implantables		
Trackers		
Exoskeleton		
Clothing	Legs	Protection
		Rehabilitation
Embedded footwear	Feet	Health metrics
		Posture correction
		Rehabilitation

Connected medicine provides a wealth of opportunity in solving novel health problems, particularly with disease management and elderly care.

In 2015, the United Nations approximated 1.2 in 10 people were over the age of 65. Projections estimate that this will jump to 22% by 2050.[132] Healthcare expenditure on the elderly is a mounting concern, as it accounts for a higher share of healthcare expenditure compared to other age groups. Equally, non-communicable diseases such as type 2 diabetes and obesity are pandemics, with the WHO estimating 600 million people will develop type 2 diabetes by 2050.[133] About 1 in 4 people suffer from two or more chronic conditions.[134] With rising pressure on governments, payers, and manufacturers to reduce healthcare costs, elderly and long-term care require solutions that are prepared for the impending rise in numbers. The Internet of Medical Things (medical IoT) demonstrates a tremendous potential to help.

Disease and Condition Management

Non-communicable diseases including type 2 diabetes, hypertension, and cardiovascular disease can be monitored by both the patient and healthcare team. Heart monitors can detect heart rate variability and alert the healthcare professional in real time. The same concept is liberating for parents of children with type 1 diabetes using smart blood glucose monitors. Blood glucose measurements are sent directly to the cloud where parents can access their children's blood glucose in near real time and be alerted to potential hypoglycemic events. Digital apps can be delivered to reverse type 2 diabetes, manage epilepsy, and improve quality of life.

Novel utilization of technology can be used to minimize the risk of health concerns and their subsequent healthcare costs. Elderly care can be delivered through digital apps. Risks such as falling, for instance, can be mitigated through fall detection and emergency assistance. Accelerometers found in phones or watches can be used to detect falls or seizures, triggering notifications to carers of an emergency, its details, and location as they emerge. Future technology could also contain safety equipment. ActiveProtective, a company from the United States, provide a care belt that detects and deploys airbags if it detects a fall.[135] Technologies such as this can help save on avoidable elderly-care and fall-rated healthcare costs.

However, the true value of the technology, especially connected wearables in elderly care, is realized in the machine learning and predictive analytics observed from the data collected. For instance, deviations from daily routines could indicate cause for concern and emerging physical or mental health concerns.

Virtual Assistants

Virtual assistants are not just entertaining; they can accompany those who live alone and provide support to the aging and elderly. Virtual assistants can empower people by answering questions, teaching new skills, setting verbal reminders to perform tasks such as reminding to take a medication and even controlling the home by performing tasks such as picking up the telephone or making a call. As homes become more connected, virtual assistants will assist people in every aspect of life and interface with all aspects of the home. Virtual assistants could call the emergency services on behalf of a patient, citing exact details and location. Connected cameras can track movement to detect falling, triggering the virtual assistant to reach out for help. Not confined to the realms of speech, virtual assistants in the form of robots can assist in particular situations within elderly care, performing roles such as helping people get of bed, the bath, or into a wheelchair. AI within such virtual assistants could even learn patterns, for example, when people may want to visit the bathroom. Interaction through voice and touchscreen enables communication and will increasingly empower aging patients with greater autonomy and reduce the burden on elderly care.

As the capabilities of virtual assistants improve, so too will their ability to determine the emotions of their master, whether it be happy or sad, excited or depressed. Virtual assistants will interpret the syntax, semantics, and tone of the conversation to check for signs of mental or emotional health concerns.

Similarly, there is an application for virtual assistants in products to assist people with disabilities. Apps can be used not only to control lights, music, and heating but also for lifestyle management. Nominet, a UK Internet organization, developed an open source prototype called PIPs to cater to people with sensory or cognitive impairments.[136] People are empowered with audio and visual prompts, nudges, and reminders to go through their daily routines and to develop the skills and confidence to navigate their environment. The prototype is built with a low energy Bluetooth controller that sends and receives notifications between devices. The devices can be used to guide people through tasks such as washing their face, taking a bath, or taking their medication.

Remote Monitoring

Connected devices can provide support for caregivers and healthcare professionals to keep people out of a hospital and reduce their visits to the doctor. Apps and virtual assistants can provide medication reminders; fitness trackers will monitor user health and movement, alerting care providers if deviations in a routine were to occur. Connected devices can alert family and care providers of events such as using a fridge, having a bath, or opening the front door. Aspects of routine demonstrated in the data would be learned and respective accounts notified if there were to be a deviation from the norm. Emergency buttons can alert the relevant services, ensuring that the elderly or those with long-term conditions can receive medical intervention when required most. The combination of connected devices, apps, and virtual assistants make the home smarter and more conducive to mitigating risk, ensuring the healthcare provider/clinic is up-to-date with the latest overview of patient health while empowering the patient.

Medication Adherence

Forgetting to take medicine is easy enough, but the implications can be a problem. More than 50% of prescribed medications are not taken as directed.[137] Missed doses can result in slower recovery time, exasperate illness, or more serious consequences. A study by Benjamin et al. showed that getting patients to take their medications appropriately could prevent approximately 125,000 deaths per year in the United States alone.[138] There are many apps and digital services that remind patients when to take their medication, but medicine is going beyond even that. Smart pills with ingestible sensors seek to help doctors improve clinical health outcomes through notifying their respective app on confirmation that a medication has been consumed.[139] The notification is triggered when the sensor comes into contact with the stomach fluid. This enables doctors to measure treatment effectiveness and optimize the patient pathway.

Accessible Diagnostic Tests

People with long-term conditions and the aging typically need increased diagnostic tests. Instead of turning up to a clinic or pharmacy to have urine and blood tests conducted, smart sensors in portable devices allow the test to be conducted in the comfort of the user's home. Results can then be wirelessly shared to their healthcare team. Tests for cholesterol, cardiac function, HbA1c, fasting blood glucose, vitamin D levels, and insulin improve the convenience of performing repeated diagnostic tests, enabling quicker treatment, reduced risk of complications, and reduction in avoidable healthcare spending. As the database and evidence base expands, so too do the application of wearables in detecting signs of disease. Type 2 diabetes, for example, can be predicted from heart rate variability collected through an Apple Watch.[140]

Smart Implantables

Implantable devices that are connected to a smartphone, healthcare provider, and wider networks will be used to monitor and treat disease in real time. The possibilities from this data are huge, as wearables are external implantables that have the potential to collect metrics on biological markers from organs and tissue.

Digital Health and Therapeutics

Telemedicine, which can be traced back to the 1900s, refers to the clinical application of technology that uses electronic technologies to support long-distance patient care, patient and healthcare professional education, and health administration. Digital therapeutics, or digital health, is an enhanced form of telemedicine that brings together digital and genomic technologies with health, lifestyle, and human factors to deliver personalized medicine to patients, enhancing the efficiency of healthcare delivery.

There are more than 150,000 apps focused on health and wellness in the Apple App Store, which have been downloaded by over 50 million people.[141] Digital health tools allow patients to take a proactive approach to their health and wellness, looking to influence aspects of human behavior for the purposes of improving health. As more of our healthcare interventions are focused on chronic rather than acute diseases, behavioral therapy is surpassing pharmaceutical intervention as first-line therapy. Digital health and wider telemedicine have applications in a plethora of health conditions and are enabling healthcare and treatments to change rapidly. For instance, patients scheduled for bariatric surgery can be prescribed a digital health app to assist in weight loss in preparation for surgery; a patient diagnosed with asthma can be prescribed a connected asthma inhaler and app; patients diagnosed with epilepsy can be prescribed an app to manage seizures.[142] Consultations through Skype of video-conferencing facilities, EHRs remote monitoring, digital health education, and transmission of scans or images among other applications, are all considered part of telemedicine.[143]

The world is truly mobile, and digital tools aim to deal primarily with minor primary care issues through electronic means. More serious issues would be escalated to the relevant healthcare professional, provider, or team. Digital health enables healthcare professionals to anticipate healthcare concerns rather than waiting for symptoms to present.

Measures of performance for digital health will be based on how convenient the experience was for the patient including patient health outcomes, quality of care, and the number of users using tools over the long-term.

Education

Digital health provides a perfect opportunity for education. Less than 1 in 10 patients with diabetes in the United Kingdom attends structured education within 12 months of diagnosis.[144] Research demonstrates offline education benefits typically decline 1 to 3 months after interventions cease, suggesting that learned behaviors change over time and further support is required to ensure lifestyle changes can be maintained. As a result, engagement with offline diabetes education courses is limited. Digital education is engaging by its very nature; it is available at any time and on any device at the patient's convenience. Digital education can additionally be personalized to users through the data exchange between user and provider with the presentation, and analysis of real-time patient data subsequently encourages personalized, goal-focused practice and sustainable behavior change. Education can be made patient-centered and person-led rather than the traditional teacher–learner environment. Digital therapeutics provide a substantial opportunity to empower patients with the knowledge, skills, and resources required to manage and optimize their health.

Lifestyle changes such as stopping smoking, moving more, and losing weight can all be tackled through behavioral interventions, simultaneously targeting the major chronic diseases. Chronic diseases and their management are behavior mediated. Digital health tools enable treatment to be personalized, democratized, and scaled. Real-world evidence has largely demonstrated the efficacy of digital tools. More evidence and randomized clinical trials are required to demonstrate causation. One area that is still unclear is who pays for digital therapeutics. If a doctor should prescribe a digital therapeutic, who should pay? The insurance company? The healthcare provider? The employer? The patient?

Regardless, digital innovation is revolutionizing disease management. Patients are increasingly demanding autonomy; wishing to be educated about their health, aware of the latest evidence base and engaged with their health.

Incentivized Wellness

Ill health is expensive. To employers and the economy, physical and mental health issues cost the United Kingdom more than £77 billion.[145] Employees lose an average of 30 working days each year due to illness or underperformance as the result of poor health. The economic impact globally chronic conditions such as cancer, type 2 diabetes, and mental illness could reach over $47 trillion by 2030 according to the World Economic Forum.[146] Individual lifestyle choices, physical and mental health, all impact work performance. There is a significant challenge mounting for providers such as insurers and employers in improving absenteeism and presenteeism. To do this, providers are realizing the importance of holistic health—comprising physical health and mental health, social and human interaction, both in and out of the workplace.

As healthcare interventions focus on chronic conditions rather than acute illnesses, behavioral therapy is typically becoming first-line therapy over pharmacological intervention.

Wellness programs provide a convenient mechanism by which employers can support health and wellness in the workplace. Previously, incentivized wellness meant encouraging individuals to visit the gym and take more steps—by taking the stairs or walking to work. Employers often promoted healthy behaviors associated with employee well-being and reduced healthcare costs. Today, wellness programs and digital tools go beyond signposting and screening. Immersive, engaging programs that are remotely accessed empower individuals to modify their behavior with the goal of achieving positive clinical outcomes, and better health. Behavior change in the form of therapy, behavior coaching, biomedical data feedback, and sensors enable wellness to be truly patient-centered.

AI

AI has been widely adopted in critical industrial roles for decades and has finally started to take a leading role in healthcare. Connected medicine has provided fertile ground for machine learning models to be developed. AI seeks to place the doctor in our pocket. Among other things, AI has applications in disease prediction, cost reduction, efficiency improvements, automating manual tasks, and promoting us to alter our health. As data volume and variety increases, the capabilities of AI models will become more precise, more probing, and also more contentious. Life expectancy from birth has stopped increasing.

Mining Records

Mining of healthcare information systems holds tremendous potential for medicine. Systems hold considerable information about patients and their health, prescriptions, doctor's notes, and more. Healthcare data within such systems can be used to improve the quality of healthcare, reduce costs, mitigate mistakes, and improve and democratize healthcare quality.

However, knowledge discovery from the data contained in such systems is currently challenging due to variations in complexity, vocabulary, and standardization. Data mining provides an opportunity to extract relevant information from both textual and image-based archives. Mining also enables the discovery of patterns from data that can be used to build predictive models.

As discussed in Chapters 3 and 4, unsupervised learning is known for feature extraction, whereas supervised learning is suited to predictive modeling. Mining of records is beneficial for both the patient and provider. Mining of records can be used to identify high-risk patients or those with chronic conditions for whom a personalized intervention could be delivered. Record mining enables providers to find best practices and treatment to reduce claims and hospital admissions. Through comparison of symptoms, treatments, and positive and adverse effects, healthcare providers can analyze the pathways that improve outcomes for patient cohorts, enabling clinical best practice and standards of care.

Conversational AI

Conversational AI refers to systems that can talk. Rather than a user interface based on text or code input, individuals can interact with conversational AI system with their voice. Users are increasingly using chatbots to communicate with products and services. Voice-driven AI such as Amazon's Alexa can synthesize natural language to provide recipes or exercise tips, order products, or call a cab. The technology is catching on: 1 in 5 Americans owns a smart speaker, and there are over 100,000 Facebook messenger chatbots.[147]

As AI chatbots develop, so too are their capabilities. Intelligent personal assistants will act as healthcare assistants. By virtue of being voice-controlled, there are immediate applications for those less-abled, where only the voice needs to be used to perform tasks or instructions. Within health, conversational AI enables simple questions that do not need the attention of a doctor to be answered. For instance, new parents could bombard a conversational AI with questions without fear of embarrassment or consuming healthcare professional's time. Questions such as what temperature a baby should bathe in, how often a baby should sleep, or whether there are developmental milestones taking place can all be instantly answered by an AI speaker. Many individuals turn to search engines to find the answers to their questions. However, most patients who query symptoms are unaware how to discern research quality and may come across conflicting evidence in addition to misleading information (or fake news) that can leave patients confused. With the assistance of a medical AI chatbot, patients can receive immediate assistance. Continuing the preceding example, if a child's new parents had a medical question or were concerned by a symptom (say, a chesty cough), it would be burdensome for them to visit the doctor for a response to every question. However, there is a need for medical confirmation. This cannot currently be detected through algorithmic means; and hence, the evolution of conversational AI in healthcare will be digital health assistants supported by and learning from healthcare teams and the world around them.

As conversational AI develops, cognitive systems will analyze conversation to detect early signs of mental, physical, or neurological illness. Voice-enabled devices such as Alexa will one day be able to identify symptoms of Asperger's, anxiety, psychosis, schizophrenia, and depression from conversational tones. This will assist doctors to predict better and monitor and track disease.

Imagine how much time and resources will be saved when virtual assistants, healthcare chatbots, and digital tools give answers to basic medical questions that do not require the intervention of a medical professional.

Making Better Doctors

AI will transform what it means to be a doctor. AI's integration into medicine is making better doctors and saving lives. From waiting times to prioritization, finding of evidence to maintaining productivity, or supporting decisions—AI will assist doctors and healthcare professionals in making informed decisions.

Optimization

Suboptimal processes waste time and resources. Scheduling systems for clinics, doctors, and patients enable healthcare to be as efficient as possible. An AI system that was to schedule patient appointments and streamline communication would lighten doctor burden and focus time on more pressing matters. If a patient presented an urgent matter, for instance, an AI could evaluate and prioritize patient appointments.

AI will enable healthcare professionals to stay up to date with the latest evidence base. PubMed, for instance, has over 23 million papers within its archives.[148] AI that was to mine such articles and present the most relevant evidence would facilitate more up-to-date healthcare professionals and enable professionals to practice medicine to the best of their knowledge and evidence base. Similarly, AI can assist healthcare professionals in administrative tasks, performing roles of cognitive assistance.

AI can help mitigate a plethora of mistakes, including those made by humans. Record mining, in particular, will enable doctors to improve over time. For instance, digitalized data regarding patients, their treatment, healthcare professionals, and clinics can be mined to identify errors in treating certain conditions and avoid unnecessary hospital admissions. Zorgprisma Publiek, a Dutch organization, currently does precisely this: using IBM Watson to mine data to identify repetitive mistakes.[149]

Diagnosing disease

Professor Geoffrey Hinton, a pioneer of neural networks, famously stated that it is “quite obvious that we should stop training radiologists” due to the sophistication of image perception algorithms, which could soon be more advanced than humans. AI can currently be used to examine medical scans, identify symptoms of type 2 diabetes, identify retinopathy and cardiovascular disease risk, and spot signs of breast cancer. AI will perform better as algorithms are trained on more data. However, it is not just clinical data that is required for disease diagnosis. Cardiogram, an organization based in the United States, can detect type 2 diabetes with an 85% accuracy rate—from Apple or Android watches, Fitbits, and other heart-rate enabled wearables.[150] Similarly, the US company Striiv can detect atrial fibrillation from 2 weeks' worth of heart-rate data. Algorithms to detect disease are showing great promise, with several already in medical practice. However, that does not mean all AI diagnostics are ready for implementation. Many AI tools are developed without peer review and its academic rigor. Essential details require verification, such as the algorithm's code, training, and validation datasets; the data to which it is compared; how performance is evaluated; and how neural networks come to their conclusions. As AI evolves, one would expect AI diagnostic tools to undergo the same RCT analysis that drugs are subject to. Diagnostic AI can save lives, money, and time through earlier diagnosis of conditions and responsive treatment.

Making and rationalizing decisions

Doctors make challenging decisions daily. It is vital that these decisions are as informed as possible. The use of AI, data mining, and predictive analytics is enabling clinicians to rationalize decisions and develop evidence-based treatment options. AI does not have to make the decision but can present the most reasonable opportunities to proceed.

Drug discovery

Developing a new drug is an expensive business, and only one in three new drugs will make it to the market. Every new drug brought to the market costs pharma an average of $2.7 billion.[151] The consequence of failed drug trials can be damaging: from reduced share price to closure of worksites and reduced staffing. Hence, the pharmaceutical and life science industry is increasingly turning to AI to facilitate drug research and development. Pharma isn't looking to replace humans. Instead, it is looking to see why the rate of failure is so high through using innovative AI. AI systems are being developed that can identify new therapies from information on existing medications; this could improve efficiency, drug development success, and accelerate the route to market for new drugs. In cases of pandemics, such as Ebola or Swine Flu, an accelerated route could save numerous lives.

There are approximately 10^{60} compounds that have drug-like characteristics.[152] The chemist of the future will be empowered through leveraging data: historical data, experimental data, inferences, and trends. AI enables the earlier identification of promising drugs and biomarkers. AI also has application in clinical trials. Clinical trial patient stratification allows the identification of patient groups most likely to benefit from the associated drug. This enables clinical trials operators to find the right patients for trials rather than patients who are unlikely to respond.

3-D printing

Innovation in 3-D printing promises exciting advances in the field of healthcare, where 3-D printing is beginning to disrupt traditional paradigms as the technology becomes more affordable and accessible. As the name suggests, 3-D printing involves printing 3-dimensional objects from a digital model, using additive processes to build the object. Also known as additive manufacturing, 3-D printing adds iterative layers, one on top of the other, to assemble the model. This allows precise modeling and reduces error. Although 3-D printing solutions are still in infancy compared to other technologies, the potential for its applications is exciting. Many AI experts consider it feasible that in the future, humans will adopt robotics and bioprinted material into their bodies. Soon humans may be able to print just about everything, from prosthetics and pills to bioengineered replacement body parts and organs. The technological advance of 3-D printing has life-changing implications for patients.

Personalized prosthetics

The World Health Organization state that approximately 30 million people require prosthetic limbs, braces, or mobility tools and only 20% have them.[153] 3-D printing enables prosthetics to be custom built for each person. Through capturing a patient's measurements, prosthetics can be tailored to ensure comfortable, custom-fitted devices. Prosthetics will also become more comfortable as multi-material, 3-D printing assists with ensuring a better integration with the human body. Casts could also be made more comfortable through the same, personalized approach. 3-D printing facilitates the swift and cost-efficient creation of personalized products. Innovation in 3-D printing is combining integrated sensors and machine learning algorithms to support more natural, fluid movements. Predictive movement algorithms will evolve to mimic more natural movement, and humans will be able to use their brain and body to control them. 3-D printing technology enables prosthetics to be modeled and constructed in a little under 24 hours; importantly, printed prosthetics cost a fraction of conventional prosthetics.

Bioprinting and tissue engineering

Kidney, liver, and heart transplants could soon be a thing of the past. 3-D bioprinting marks the beginning of an era where transplant lists are a thing of the past. 3-D-printed organs can be built using the same techniques as 3-D printing, but instead use stem cells as the printing material. As well as printing cells, bioprinters typically output a gel to protect cells during printing. In the future, once these organoids are printed, they will be able to grow inside the bodies of patients. Princeton University has developed a bionic ear from 3-D printing tools, which can hear frequencies beyond the human range. Printable and customizable implants from a patient's cells reduce the potential risk of rejection from the body.

One use case for bioprinting is the 3-D printing of human skin. Burn and acid victims, for example, have limited options for their disfigured skin. A team of Spanish researchers developed a 3D bioprinter that was able to produce human skin cells. Within 30 minutes, a biological ink containing human plasma and other materials was able to print 100 square centimeters of human skin.[154] The opportunities bioprinting technology enables are truly life-changing.

There is no doubt a cosmetic market for bioprinting. It is feasible that in the future, face printers could be used by people to apply a model of someone else's face to themselves, or even store a digital model of their face and regularly reprint their face for perpetual youth.

Alongside nanotechnology and genetic engineering, bioprinting may prove a tool in the pursuit of extending life spans.

Pharmacology and devices

3-D printing disrupts traditional pharmacology and device manufacturer approaches. For instance, the efficacy of drugs and other treatments can be tested on replicated human cell tissue. Through this, 3-D printing enables the printing of medications that are personalized for the patient. By reducing drug variability with this approach, there is potential for 3-D printed drugs to increase medication efficacy, reduce adverse effects, and improve adherence. The same concept applies to device consumables. Blood glucose test strips, for instance, could be 3-D printed for use by diabetic patients at home. The possibilities are endless.

Education

Alder Hey Children's Hospital in Liverpool, England, uses 3-D printing for teaching and familiarizing stakeholders with heart surgeries that are to be performed.[155] Every cardiology patient is unique; and for those undergoing operations, 3-D models are printed to enable a variety of uses. Firstly, it enables surgeons to demonstrate surgeries that will be performed to often anxious and concerned parents using textures and colors that closely represent human tissues. Secondly, the 3-D models are used by staff and surgeons to familiarize themselves with the most important part of an operation—the child's heart. Finally, 3-D models are used to train students.

3-D printing also enables surgeons to prepare before surgery through evaluating a precise model of the patient's body or organs. This mitigates the likelihood of errors, improves surgeon accuracy, and reduces the amount of time the patient is required to be on the operating table. 3-D modeling is also useful in modeling bodily organs without the need for invasive procedures.

Gene therapy

Just like organ transplant lists, genetic diseases could soon be a thing of the past. The use of nanotechnology, which refers to working with tiny particles to manipulate cells and alter DNA, enables the editing of gene expression at a cellular level. For instance, gene editing has been successfully used to modify human immune cells to resist HIV infection. With 1 in 25 children born with a genetic condition, gene editing has the potential to treat or eliminate disease.[156] It could be used to correct defective genes in embryos and personalize the child's immediate healthcare treatment plan. It is feasible that genetic conditions like cystic fibrosis, sickle cell anemia, and muscular dystrophy could be treated through editing the DNA in patient cells. Gene editing is not without ethical implications: many people have moral and religious concerns about the use of human embryos for research or the editing of genes. Also, there is a concern that nanotechnology and gene editing will only be available to those that are wealthy, which will exasperate the disparity in healthcare and interventions. Nanotechnology will significantly improve treatment and recovery time, with the absolute potential to prevent humans from developing disease at all.

Virtual and Augmented Reality

In the not too distance future, surgeons performing CT scans will be able to layer their scans over a patient's body via augmented reality; medical students will use virtual reality to explore the inside of the heart and burn victims will be virtually transported to a snow-covered mountaintop as a form of pain relief therapy. Immersion into a completely digital environment, virtual reality, has mainly been used for games. Innovation in augmented and merged reality means that we can now entwine the virtual and physical worlds and manipulate both environments simultaneously. Virtual, augmented, and mixed realities are increasingly being implemented in a wide range of medical applications. It is already evident that as it is incorporated further into healthcare, it has the potential to change the way many healthcare services are delivered.

Virtual Reality

Virtual reality (VR) is typically associated with gaming. In virtual reality, the user's reality is replaced by an immersive, entirely digital environment. This is currently achieved through a headset and handheld sensors, which enable interactions within the environment.

Augmented Reality

Augmented reality (AR) overlays a digital or 3-D environment in the form of objects, video, or data into the user's environment. The user's real-world experience remains central to the user's experience, and the information is added to the user's existing reality to enhance their experience. Information is distinctly digital and does not seek to emulate real-world objects. AR does not necessarily require additional hardware and can be achieved through technology such as the mobile phone. AR's popularity was confirmed by the Pokemon Go app phenomenon in 2016. The game, downloaded more than 800 million times, overlaid 3-D characters within the user's real-world environment through the user's GPS location and inspired a wave of AR innovation.

Merged Reality

Merged reality seeks to emulate digital objects that can be interacted with. This requires additional technology such as a headset. Separate sensors track hand gestures and movement. In a mixed reality, the user can manipulate both the real-world and digital environment.

Pain Management

Research demonstrates that virtual reality environments can be used to reduce the amount of pain a human feels versus a control distraction condition.[157] The somatosensory cortex and insula, found in the brain, are linked to pain. Hence, through immersing patients in a virtual reality, VR will be used to enable patients to endure painful surgery. Amputees often report pain in their amputated, missing limbs. VR environments can be used to immerse the patient within an environment to better cope with their phantom pains.[158] VR also works as a distraction. In the future, children and adults alike will be given a VR headset from their doctor when receiving an injection to distract them from the impending prick. Hermes Pardini Laboratories and Vaccination Centres piloted the use of a VR headset that immerses the patient into a fictional, gamified environment.[159] The patient is distracted in a virtual world to the point that they are often unaware they have received their injection.

Physical Therapy

VR can track human movement, allowing patient movements to be monitored and analyzed. VR gyms have been opened in San Francisco and Ohio.[160] Rehabilitation will become gamified, for instance, through kicking a virtual ball or catching a ball. Recovery exercises can be delivered and tracked in a VR environment and retold to the patients if they were not to get it right.

Cognitive Rehabilitation

The application of VR and AR in fears and phobias is apparent. Performed as a medical treatment, patients can be gradually exposed, known as graded-exposure therapy. Data from sensors will be assessed to ensure patient safety and develop best practice.

Cognitive function can be improved for patients struggling to perform everyday tasks. For instance, through monitoring the performing of patient tasks in a VR environment, a doctor could determine declining memory loss and identify areas of concern or priority. Similarly, patients with injuries to the brain or those that struggle with tasks can have digital environments created to represent real-life scenarios. Patients can practice tasks and regain or develop cognitive function. Patient engagement can be monitored and analyzed to observe areas of difficulty or reduced attention. There are few randomized controlled trials that have been conducted into VR in cognitive rehabilitation. However, some applications of VR are effective in treating cognitive deficits in people with neurological diagnoses.

Nursing and Delivery of Medicine

VR and AR will develop to become part of standard medical training. Both types of reality can be used to improve outcomes by enriching the information available to the individual. For instance, Alder Leys

Children's Hospital in England uses a VR headset and 360-degree video to train student doctors how to deal with stressful situations. Critical decision points can be reviewed and analyzed with peers and staff. Virtual reality will be used more to learn medical specialties such as performing operations and anatomy. Operations can be practiced with an expert monitoring and giving feedback in real time. The Royal London Hospital conducted the world's first VR surgery in 2016,[161] enabling viewers to watch in 3-D 360. The learning experience is unparalleled and has the potential to disrupt medical training, particularly for countries that have limited healthcare resources. In the future, doctors will use augmented and mixed reality to enrich their environment. Surgeons will have access to critical information in real time through mixed realities, delivered to their vision through glasses. Nurses, for instance, could use augmented or mixed reality to identify veins in the arm for a blood test. The Interventional Cardiology Center at Tufts Medical Center in Boston uses VR to introduce the facility to prospective patients with anxiety before a procedure.[162]

Virtual Appointments and Classrooms

As the cost for virtual and merged reality devices becomes more affordable, virtual appointments will become commonplace. Virtual appointments remove the inconvenience of attending a clinic, saving time, environmental resources and focusing healthcare professional time to where required. Virtual appointments will become as familiar as webinars, enabling stakeholders to be present without traveling. As well as one-to-one appointments, virtual and merged realities provide an immersive and engaging experience suited for learning. Virtual reality will become a staple tool for education and training—for both healthcare professionals and patients alike.

Blockchain

Transitioning of traditional patient health records to the EHR is considered to be enormous progress for healthcare. The digitalization of patient records mitigates some of the traditional risks of centralized data stores. However, this model still places the medical records in the hands of the provider. Blockchain technology, popularized by the bitcoin cryptocurrency, has the potential to revolutionize data access, privacy, and trust. Currently, blockchain is yet to be deployed for mainstream healthcare.

Blockchain, fundamentally a collection of data records, is a piece of software formed by the combination of several preexisting technologies that provide blockchain with its characteristic features: an immutable, distributed public ledger whose authenticity can be verified by anyone: those who validate the data on the ledger are rewarded with value, which helps create trust in a trustless environment; distributed peer-to-peer control, which provides a high level of security; and the ledger can be programmed to trigger automatic transactions in the form of smart contracts, allowing for a widespread application of this technology.

PayPal, Visa, and Mastercard, for instance, act as central authorities for financial transactions: trusted institutions that act as intermediaries. The land registry acts as the trusted store for details on homeownership. These centralized databases are subject to being hacked or manipulated. Blockchain technology aims to solve data management, privacy, and security issues, improving interoperability and easing the flow of data between doctors, hospitals, healthcare systems, and insurance providers through the use of a decentralized, immutable database. Patients are demanding increased access to their medical health records, with iOS 11.3 even including an EHR feature.[163] Data from EHRs IoT, wearables, and devices can be used within the ledger, in a trusted, secure, transparent, and interoperable environment.

The blockchain is an immutable database that is stored and maintained by all those using it. Each new transaction or piece of data is encrypted and then approved by a particular proof-of protocol (consensus, work, stake) by other nodes on the networks that authenticate the transaction or verify the stored piece of data.

Each node on the network has an identical copy of the blockchain; and thus, the transaction is permanently recorded and linked to previous records. The links, known as hashes, are traceable back to the very first block in the blockchain. Therefore, any attempts to tamper with a block in the present would require the transaction and all related blocks to be also altered, on all records, distributed among the nodes holding a copy of the ledger simultaneously. The longest chain of events is considered valid. Blockchain implements crypto-economic and game-theory techniques. Any attempt to create a rival chain would need to be created faster than the current version of the truth to be accepted. This would require tremendous computing, energy, and resource commitments. Miners compete to validate blocks. This good behavior is expensive regarding electricity and computing power, and so miners are incentivized to validate blocks, rewarded with bitcoin (BTC; in the BTC scenario). Through creating a common, distributed, immutable database of healthcare information, doctors and healthcare providers have the potential to access medical data from any system, with improved security and privacy, less administration, and better sharing of results.

- Single points of failure are eliminated by decentralizing and encrypting the data.
- The blockchain is democratized. Anyone can contribute or store a version of the truth.
- Through ensuring consensus on events, the most likely version of the truth is held.

- A transparent and auditable ledger of events is provided through time-stamping.
- Game theory, crypto-economics, and hashing incentivize good behavior and ensure the events are without censorship.

Blockchain technology has many applications in healthcare, with most technology currently in pilot or proof of concept stage.

Verifying the Supply Chain

The first application of blockchain is verifying the supply chain. As the blockchain is created in a chronological and auditable manner, it can act as a means of verification for components of every link in the supply chain. The journey of materials or treatments, for instance, can be logged onto a blockchain ledger, which could be used to identify fraudulent activity, anomalies, error, or a break in the chain through data entry or IoT devices. For instance, the cold-delivery chain of delivering insulin from manufacturer to pharmacy could be confirmed to be untampered and appropriately cooled. This is currently being used in developing countries to combat counterfeit medication. It is also being developed to enhance genomic data protection, addressing the privacy challenges of big genomic data.

Incentivized Wellness

Blockchain technology could be used to incentivize wellness: through the use of a cryptocurrency as a digital token of value. Engaging people with health services or a healthier lifestyle could save the global economy a tremendous amount of money in healthcare costs. Health providers or employers typically see the cost benefit of this in the form of savings or profit, and this is rarely passed to the individual. By utilizing blockchain technology, tokens could be created and distributed to patients through the blockchain to share the value of the savings and be treated as a tradable currency.

Individuals could earn tokens through behaviors such as going to the gym, reaching their step goal, attending education sessions, engaging in mindfulness, completing a particular sports event, or adhering to medication or digital therapeutics. The ecosystem rewards positive behaviors with an asset, or token of value. The value of the token could be fixed. Extending this concept, positive health behaviors could be extended to the point where patients have health token savings accounts that could be used to transact in hospitals.

Patient Record Access

Patients are demanding access to their health record. This poses a significant challenge as to how to best share sensitive medical data with unknown third parties. For third parties, there is also a challenge to verify the integrity of the data while ensuring privacy for the patient. Presenting patient records on an appropriately permitted blockchain would give cryptographic assurance on data quality without any need for human involvement. Providers or consumers uploading health data would generate transactions. Users provide a signature and timestamp, alongside a private key to access data. By using digital signatures, all records stored on the blockchain can be identified and used to create a comprehensive patient health record. The use of digital signatures and cryptographic encryption ensures data travel securely and are accessible only by those with the relevant public keys. By using blockchain technology, each addition to the EHR can be logged, with an immutable, auditable trail of transactions, while ensuring the most current version of the record is used. Patients would be able to verify all attempts to access or process data. Blockchain's decentralized structure enables any approved stakeholder to join the ecosystem, without the need for data integration or manipulation concerns.

Robots

The use of robotics is changing healthcare, although it will be some time before robotic technology will be widely affordable or implemented.

Indeed, it is also unlikely robots will entirely replace humans in the medical setting. Currently, hospitals and healthcare systems are unable to meet the cost of the technology; and robotic assistants have not, and some would say cannot, replace human contact. Over and above its use in the supply chain, robot technologies have potential in the following areas.

Robot-Assisted Surgery

Robot-assisted surgery enables enhanced vision, improved precision, and dexterity. Currently limited in reach, robot-assisted surgery will become commonplace as barriers to entry such as the cost of hardware and training are reduced. In the future, healthcare professionals may have to learn how to use an instrument as well as how to perform the surgery. Robotic-assisted surgery blurs the lines of liability, which could prove to be a barrier to adoption.

Exoskeletons

Robotic exoskeleton technology focuses on enabling patients to perform tasks through the use of an external, integrated device. Ekso Bionics is an organization that provides a wearable exoskeleton that assists spinal cord injury patients to stand and learn to walk. In the future, exoskeletons will become a standard form of rehabilitation and aid human mobility in more activities, and in more environments.

Inpatient Care

Inpatient care can be enhanced through the use of robots for streamlining tasks. Robots could be used to automate tasks such as collecting mail or delivering blood. Delivery robots will deliver medications or important material autonomously. Robots are already being used to disinfect rooms, where the risk to humans is minimized through using a robotic agent.[164] Soon, ingestible agents and smart pills will be able to monitor a patient's internal reaction to treatment; robotic nurses will become commonplace for automatable tasks, such as taking blood. A robot will take your vitals and draw blood by identifying the correct vein with greater accuracy than a human nurse. Robots will be used to support care for the elderly and those with long-term conditions.

Companions

Virtual assistants are becoming more human-like with developments in natural language processing. As discussed previously, humans are already forming bonds with robots. Robots can be used to provide companionship or treat loneliness in cases of mental health, elderly, and long-term care. As robots evolve in their capabilities, robots will be able to perform increasing healthcare duties such as bathing patients, transporting patients, and so on. Robots will be able to monitor vital signs through IoT and wearables and aid the patient in real time.

Drones

Drones have the potential to alter the way medicine is delivered. Drones can be used in hard-to-reach areas, places of conflict, and remote populations to deliver medication, vaccinations, and diagnostics. Drones will be used to deliver medications from the pharmacy, just as they are being used in shopping. Time-sensitive items such as blood, bodily fluids, and organs can travel shorter distances to go directly to where they need to be, within campuses or across larger distances. Drones can also be used to locate and identify, particularly in remote locations. One use case for drones is as a flying medication toolbox in cases of emergency. Critical care in the minutes after a stroke, trauma, or heart failure is essential to accelerate recovery and prevent death. An ambulance drone prototype, developed by Tu Delft, combined a heart defibrillator, medication, and two-way radio that could be dispatched to a patient to speed up the response before the first responder.[165]

Current restrictions in the use of drones are reducing their potential. It may be some time before flight restrictions, legislation, and functional issues such as drone battery life and drone load are resolved.

Smart Places

Intelligent homes, hospitals, places, and things promise to change the way we live. Ubiquitous connectivity and an expanding sensor base provide a wealth of opportunity to people, patients, and providers alike. Improvements in patient lifestyle and healthcare have contributed to growing numbers of centenarians over the past 30 years. In the United Kingdom alone, the number of people living to 100 increased by 65%.[166] These breakthroughs have come at a cost to healthcare; and smart places, and smart things, enable scalable opportunities to improve health and social care—reducing costs per capita while personalizing the experience to the patient. Rather than going through the process of connecting and integrating apps, sensors, or devices, connected places will use automated sensors that do not require the user’s constant attention, collecting tremendous amounts of real-time data. Facial recognition, voice recognition, responsive notifications, and data-based suggestions will become the norm. Aggregation and analytics platforms will streamline and simplify decision-making processes in a rapidly changing environment.

These devices can notify patients and healthcare professionals in real time: forget your Big Brother, this is Big Doctor.

Smart Homes

There will be many ways that homes will become smart in the pursuit of improved patient and population health, which are best illustrated by example. On waking, a wearable sleep monitor will assess the quality of your sleep while you perform mindfulness through your connected watch. Your sleep monitor will even tell you when to go to bed for optimum recovery. After brushing your teeth with a toothbrush that assesses whether you are hydrated or not, you drink your morning coffee, which controls the dosage of insulin released for absorption in your bloodstream. Your fridge will inform you of out-of-date food and ensure none of your potential allergens are found in the food you purchase. Smartphone apps will augment the calories, and nutritional values of foods; and 3-D printers will enable the printing of safe-to-dispense, at-home pharmaceuticals. Virtual assistants and even mirrors will assess for signs of anxiety and depression and assess health biomarkers in natural language. Should you develop a cough, your virtual assistant will tell you that you're coughing more than usual; and with the change in body temperature detected from your smartwatch, your assistant calls the doctor on your behalf and arranges an appointment. As a closed environment, the smart home allows for AI to accommodate for the highly individualized needs of the user. The most important element aspect of smart anything is the nuance when scaling: to understand the context and prioritize local activity.

The future is not as far as it seems. Bolzano in Italy is already working with IBM and various partners to empower aging people to age safely at home.[167] Safety and security are the main priorities, with the project using sensors installed into homes to monitor environmental factors such as temperature, carbon monoxide, and water leaks. Data is pushed to an off-site control room where, depending on the individual need, family members, volunteers, emergency response staff, and social services are notified.

Smart Hospitals

A smart hospital is one that is connected, much like the smart home. The objective of a smart hospital is to provide clinical excellence, an efficient supply chain, and superb patient experience—facilitated with technology. Smart hospitals will use a continuous learning ecosystem, ranging across many areas including electronic data collection and health records, digital technology, robotics, 3-D printing, unstructured data, and robust analytics. Somewhat ironically, mass use of technology and AI will enable patients to become more actively involved in their treatment decisions. Non-emergency consultations will take place on the Internet, with AI prioritization enabling the right doctor, with the right skills and training, to treat the patient. Treatment will be blended between offline, physical care and digital care—where adherence and accountability can be quantified and maintained. Growing data and large-scale analytics will continue to personalize digital treatments for patients.

On attending a hospital, an automated and streamlined admission reduces patient waiting time. On admission, patients will be tagged with a clinical-grade wearable to track vital signs through the inpatient stay. Metrics are all sent wirelessly to a dashboard visible to your medical team. Any anomalies or causes for concern are detected and prioritized. Hospitals and surgeries will become hubs of data, with hospitals working with business to extract value from the data—regarding improving efficiency, minimizing mistakes, and for improving treatment and device decisions. Healthcare will be delivered as a service, with patients incentivized with cryptocurrency to maintain sensible and healthy lifestyle choices. All relevant data will be anonymized and accessible to digital health partners and internal departments to enable continuous learning from each patient's experience.

Reductionism

The basic premise of reductionism is that by breaking down or simplifying complex biological or medical phenomena into their many parts, one is much more likely to understand a single cause and devise a cure. Reasoning is reductionist. For instance, a mouse can be divided into a skeleton, a circulatory system, a nervous system, a digestive system, and so on. It fits a model—a pattern, theory, equation, formula, or some form of common structure. AI systems also follow the same, reductionist approach; reducing the problem to a defined discipline. For AI to truly develop artificial understanding, the key will be to address humans from a perspective of holism.

As the world continues to immerse itself in digital technology, healthcare AI models are becoming quicker and more accurate, with patient-based care and lifestyle medicine placing the focus back on holistic health. The effect of lifestyle factors, sleep, movement, nutrition, environment, and genetics on health is well known. And we know that the world and people, mind and language, can be unpredictable. As AI develops, problems of irreducible complexity will require solving where the reductionist approach cannot work. The focus is on value, on the patient; treating patients as people and focusing on the patient's wider health, relationships, and goals. As AI grows, so too does the requirement to not lose the human touch.

Innovation vs. Deliberation

While AI and digital health hold significant promise, healthcare is facing significant challenges in coping with the rapid drive to integrate these systems into medicine—where the stakes are high. Meaningful changes in healthcare will come from the right blend of innovation and deliberation. As the boundaries of discovery are tested, the potential of providing more patients personalized and precise care is realized. At the same time, there is an obligation to explore and anticipate the social, economic, political, and ethical consequences of innovation.

AI's adoption in healthcare is best managed as a gradual development, which would be useful for stakeholders to have time to map and understand the possible consequences of its implementation. Robust standards are required for auditing and understanding AI models to uphold quality assurance and trust. Academic research, clinical evidence, and policymaking are also required on the use of AI systems in healthcare. The development of AI standards requires a diverse and public forum that is academically robust and reviewed periodically in line with the latest evidence base.

Awareness within the medical professional and patient communities is required. Healthcare professionals need basic knowledge of how AI applications function in their respective medical settings to understand the advantages, disadvantages, and consequences of how AI can facilitate and assist them in their everyday tasks. Patients must become accustomed to engaging with AI systems and explore the benefits for themselves. Demonstratable examples of how AI in healthcare is optimizing efficiency, optimizing resources, and improving population health outcomes will strengthen the public perception of AI.

Organizations working with AI need to communicate and engage the general public about the potential advantages and risks of using AI in medicine. Organizations developing AI must work with academia to take the necessary steps to be able to measure the success and the effectiveness of AI systems independently. It is vitally important to encourage affordable AI solutions to democratize AI as the stethoscope of the twenty-first century; and published, validated evidence and literature is essential to trust and adoption. Here's to the most hopeful era for healthcare yet.

CHAPTER 8

Case Studies

AI is improving the healthcare experience, bringing success to those who can leverage and adapt to a new health and care delivery paradigm. The proceeding case studies provide unique and engaging perspectives of the use of big data, AI, and machine learning within healthcare. Real-life descriptions of organizational approaches to data-identified healthcare problems demonstrates the instant value within available data.

Several enthusiastic and responsive healthcare organizations submitted a case study for inclusion within the book. The focus of case studies was real-world demonstrations of AI, machine learning, data, and IoT usage that were novel and innovative in their provision. As well as describing what success looked like, and how it was achieved, the aim was to bring light to the inertias and developed learnings encapsulated within systems.

Case Study Selection

A call for case studies was placed on Twitter and we received over 60 case study applicants. Case studies were only accepted on the proviso that the application was deployed in some guise, whether pilot or otherwise, and case studies were supported with evidence to demonstrate value from a

A. Panesar, *Machine Learning and AI for Healthcare*,
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financial and/or patient perspective. The criteria used to evaluate case studies was the following:

- Focus on delivering precision medicine
- The case study focused on a machine learning or data-driven model that was in existence, in production, and deployed
- Case studies focused on learnings from the projects
- Case studies required authors to share adequate information on the project scope and conclude on the organizational, business, clinical, or financial impact

The case studies chosen for inclusion have been validated and contain applications that exist in healthcare today. Case studies comprise the following:

- AI for Imaging of Diabetic Foot Concerns and Prioritization of Referral for Improvements in Morbidity and Mortality—Harkrishan Singh, Gro Health
- Outcomes of a Digitally Delivered, Low-Carbohydrate, Type 2 Diabetes Self-Management Program: 1-Year Results of a Single-Arm Longitudinal Study—Laura Saslow, Jim Aikens, and David Unwin
- Delivering a Scalable and Engaging Digital Therapy for Epilepsy—Charlotte Summers, Diabetes Digital Media
- Improving Learning Outcomes for Junior Doctors Through the Novel Use of Augmented and Virtual Reality—Alder Ley Children's Hospital
- Big Data, Big Impact, Big Ethics: Diagnosing Patient Risk from Data—Dom Otero, Diabetes.co.uk

Conclusion

Case studies contained within this chapter showcase the potential of data-driven systems, AI, and machine learning in healthcare. The case studies selected showcase a tremendous vision, focus, and drive to improve patient engagement, outcomes, and clinical success. Showcased case studies serve as stimulating examples on the topics of the following:

- The use of data to drive decision-making and provide patient- and population-scale precision medicine
- Advantages and pitfalls of developing machine learning models
- Data collection, analysis, and governance
- Developing intelligent agents and the blend between digital and offline healthcare
- Ethics of AI and morality
- The future of healthcare and digital technology

Case Study: AI for Imaging of Diabetic Foot Concerns and Prioritization of Referral for Improvements in Morbidity and Mortality

Harkrishan Singh, Head of Machine Learning, Gro Health, United Kingdom

Background

Over 400 million people globally have diabetes, a condition of high blood sugar (glucose) call hyperglycemia. The two main types of diabetes are type 1 and type 2. Chronic hyperglycemia can cause recognized complications of diabetes including foot problems. Due to prolonged high blood glucose levels, people with diabetes may have slower wound healing times. They may also have reduced nerve functioning called peripheral diabetic neuropathy. This means the nerves that usually carry pain sensation to the brain from the feet do not function as well, and it is possible for damage to occur to the foot without feeling it.

Treading on something, wearing tight shoes, cuts, blisters, and bruises can all develop into diabetes foot ulcers. Narrowed arteries can also be a consequence of diabetes, and reduced blood flow to the feet can also impair the foot's ability to heal properly. When the foot cannot heal, a foot ulcer can develop. Foot ulcers are a common complication of poorly controlled diabetes, forming as a result of skin tissue breaking down and exposing the layers underneath. Chronic poor blood supply can contribute to the risk of requiring amputation of toes, feet, and lower legs. Approximately 2.5% of the population with diabetes have foot ulcers at any given time, which in England alone is 68,000 people. £1 in every £140 of NHS spending is on ulceration and amputation. Those who wait longer for specialist care tend to have more severe ulcers, and their ulcers are less likely to have healed at 12 weeks. Only 20% of patients are referred to a foot protection service within the National Institute of Clinical Excellence (NICE)-recommended time frame of 1 day.

In 2014–2015, 1 in every 390 people with diabetes were admitted to the hospital for an amputation; and 1 in 33 people with diabetes were hospitalized due to a foot ulceration. The combined NHS cost for inpatient care was £322 million (86% on ulcer-related admissions).

Inpatient improvement programs delivered by video to promote foot checks and reduce ulcers have been successful. Ipswich Hospital NHS Trust saved an estimated 19 foot ulcers and 571 diabetic bed days per year, saving £246,000 annually. The cost benefit from improved foot self-care, referral, and diagnosis is substantial. NICE guidance recommends those with an active foot problem should be referred to a multidisciplinary team (MDT) or foot protection service within one working day and triaged within one further working day. The National Diabetes Foot Audit (NDFA) found that 20% of 9,137 patients followed were seen in this time frame.

Cognitive Vision

Cognitive vision or image recognition is a machine learning technique designed to mimic how the human brain functions. With this technique, machine learning models are taught how to recognize visual components that make up an image. Through learning on large datasets of images and identifying patterns, models are able to make sense of their input and determine relevant tags and classifications. Image recognition is not an easy task. To successfully perform image recognition, neural networks are the technique of choice. However, even still, the computation resource cost is expensive in practice. For instance, a 20-pixel by 20-pixel image received by a neural network would receive over 400 inputs. Although this sounds achievable in a typical hardware setup, images of greater size, say 1,000-pixels by 1,000-pixels, would require a powerful computational resource to process the higher number of parameters and inputs. In a traditional neural network, each pixel would be linked to a single neuron. This is computationally expensive.

Proximity of pixels within images has a strong relationship with their similarity. Convolutional neural networks specifically make use of this feature. Rather than treating two nearby pixels as distinct, convolutional neural networks assume there is more likely a relationship between these pixels than two that are further apart. Through bypassing less significant connections between pixels, convolution solves the computational and time problems faced by traditional neural networks. Convolutional neural networks improve the computational resource required for image recognition through filtering relationships by proximity.

Clinical evidence suggests that diagnostic tests and risk stratification can predict the risk of ulceration and amputation, with early referral reducing amputation rates and time to heal. Solutions for diabetic foot care must be broader than the standard healthcare worker dependent service and be deliverable at a lower cost for the patient and healthcare system. Together with my colleague Yang Wang, we applied state-of-the-art AI techniques to automatically detect signs of diabetic foot concerns, alert the patient, and support communication and assessment by the healthcare team. Image recognition technology for diabetic foot concerns would be revolutionary, particularly considering this machine learning experience could improve ulceration healing time, cost, and risk of amputations—as this is related to how early ulceration is detected. The model has achieved high accuracy in detecting subtle areas of bruising and cracked heels, which can soon develop into areas of foot ulceration.

A cloud-based system was developed to allow remote use of the application such that any device with an Internet browser was able to upload an image alongside a standardized protocol. The output would be a list of any concerns detected, the referral pathway most suited to the concern, and education, if relevant. The model is constantly refined through a machine learning feedback loop that optimizes and retrains the model periodically with random subsets of labelled data, including the data received from the web-based system.

Project Aims

The aims of our project are to further develop and validate this machine learning technology, including the deep learning neural network used to predict the risk of foot concerns and provide precise medicine to patients. The convolutional neural networks used for multiple predictions can become more precise through its use and feedback loop from users. As the user base is largely healthcare professionals and carers, the learning can be scaled up and validated by the healthcare professional for appropriate triage. The project also aims to deliver a service provision to patients, which is only possible when the model has reached maximum, and ideally near-absolute, accuracy. Reducing error is a key priority for the project. Grading schemes and standardized protocols support the model to develop greater precision and recall. The ability to identify ulceration and other foot concerns earlier would accelerate diagnosis, treatment, and save the lives of many. A cloud-based system would enable easier sharing of the application and its outcomes. A catchall event log was developed to identify all events taking place within the ecosystem. The platform includes behavior health mentoring and integrated tracking for blood glucose, blood pressure, mood, food, weight, and sleep through Bluetooth-enabled devices, wearables, and self-inputted data.

AI models provide boundless opportunity in predictive analytics. By analyzing and generalizing on thousands of images, medical images are being turned into science. Precision medicine is the objective of evidence-based medicine. There are few ways as engaging and immersive as digital, which enables healthcare to collect enormous amounts of data; analyze and provide useful feedback to inform patients; and prevent, predict, diagnose, and treat disease. By the very nature of imagery, de-identification for aggregated learning is technically simple. However, the requirement to be able to explain the mechanisms of deep neural network prediction is technically difficult. A more general understanding of the application alleviates most stakeholder concerns, which can be explained through demonstration. As a novel innovation, there has been a requirement to explain how models are generated, validated, and continually evaluated. Regulatory approval has proved more laborious than previous projects due to the loose definitions that exist around product categorization. Error minimization has been a priority, and regulatory approval has focused on ensuring patient safety. The risk of false positives was determined to be more likely: early ulceration detection means quicker healing and less risk of amputation. Thresholds of concerns were developed within the model, with any doubt referred to a human.

Outputs of the project are being documented through clinical papers to highlight the value of the project to patients, healthcare providers, and global healthcare providers. Perhaps of most significance, the outcomes will demonstrate how people with diabetes can achieve significant health improvements by preventing and detecting diabetic foot problems.

Challenges

There were a number of inertia points that were observed through the duration of the project:

- **Quality of data**

  Any model can only be as good as the data that is used to create it. Data completeness and correctness are paramount for a robust machine learning algorithm. There were several significant challenges with the datasets collected that facilitated the development of robust data governance processes. First, lack of labelling meant that data was unlabelled and often unclear on receipt. Second, handwritten notes that supported image scans were often illegible. Incorrect spelling or incomplete doctor notes complicated the data validation process. The cleaning and vetting data advanced a dataset that was established as a source of truth for the model.

- **Data governance**

  The requirement for national and international regulatory approval required appropriate, transparent data governance processes to be in place. Governance-covered areas included data architecture, archiving, management, metadata management, privacy, security, and validation. Standards, best practices, and procedures were developed for data acquisition, verification, and validation. A central repository held all relevant data and metadata, with access restricted by credentials to ensure appropriate user management.

A governance trail for all decisions was noted as per the requirements for regulation, which provided an opportunity for reflective learning as the project ended. Stringent data governance ensured the integrity of data used within the project.

- **Performance vs. "explainability"**

  Neural networks are notorious for being difficult to explain, particularly as models become more complex. A key requirement of this project was transparency in algorithmic decisions. As the model developed, iterations of learning and backpropagation tailored nodes within the network that became unexplainable. Model performance and accuracy was secondary to model transparency.

- **Ethical governance**

  Strict data ethics and information ethics governance procedures were developed alongside data governance processes to ensure ethical and moral use of data. The machine learning model was used by healthcare professionals to predict and diagnose risk of foot ulceration. Processes around the effect of false positives and true negatives in particular were noted, as misdiagnosis was established to be the greatest ethical concern. The effects of ulceration and healing times can be greatly reduced through swift diagnosis and action. As the application was used to support the actions of healthcare professionals, users were informed as to the limitations of the model, and it was explained how model accuracy was based on validation datasets.

- **Closing the loop**

  The developed model predicted the likelihood of foot ulceration and other diabetic foot concerns. As this was to be used in the stages of prevention and diagnosis, a feature that was requested was the ability to validate and confirm model predictions. To do so, the healthcare professional using the application would either confirm diagnoses or refer the patient to a specialist for diagnosis. The process of feeding back patient outcomes into the system enabled the system to learn in near real time. Data feedback from patients once referred to the hospital was difficult and cumbersome to gather.

- **Stakeholder understanding**

  An unforeseen challenge was the lack of stakeholder understanding and sporadic resistance to technology-driven healthcare solutions. Key stakeholders were typically biased by previous experiences, negative press, or threatened by concerns of an age of robots taking jobs from humans. This was overcome with staff stakeholder training days; third-party experts and internal stakeholders explained how AI and machine learning could be used to optimize the tasks conducted by healthcare professionals, improve the resource burden, and mitigate concerns of a near-future robot race. The project scope was developed with the input of a diverse, multifaceted stakeholder group to ensure all relevant parties were vested in the project.

- **Adoption strategy**

  As a project that started through R&D funding, there was little incorporation of the pilot project into the wider organizational direction. Stakeholder comfortability and adoption of the novel innovation was progressed through workshops and hands-on experience. Workshops focused on mitigating stakeholder concerns and on the ease, efficacy, and resource-light environment of the predictive system.

Conclusions

Cloud-based intelligence that is sensitive and accommodating to differences in photography hardware and formats can be combined with patient clinical, demographic, behavioral, and genomic data to develop a precision-medicine framework for detection of diabetic foot concerns. The prototype was welcomed by healthcare professionals, with several remarking on elements that improved their own knowledge on the topic. Healthcare professionals felt more confident in diagnosing foot concerns when partnered with the digital tool. Digital assistance can confirm and support decisions and challenge healthcare professionals on how they arrive at their decisions. Applied across the spectrum of medical images and data collected by healthcare and research organizations, the technology will affordably be able to enable large-scale prognostic, risk stratification, and best treatment decisions.

From our experience, having more data is almost always more important than the algorithm itself. Overcoming the concerns of text digitalization and label recognition alongside medical imagery proves to be a challenging area within this field. Handwriting and human error have been the biggest problems to mitigate to reduce false recall. Conducting a large-scale clinical trial is the next phase of the project. A pilot project assessing the feasibility of the project is pending funding approval.

Case Study: Outcomes of a Digitally Delivered, Low-Carbohydrate, Type 2 Diabetes Self-Management Program: 1-Year Results of a Single-Arm Longitudinal Study

LR Saslow, PhD, University of Michigan, Ann Arbor; JE Aikens, PhD, University of Michigan, Ann Arbor; DJ Unwin, FRCGP, Principal in General Practice, The Norwood Surgery, Southport, UK

[*The following details the Low Carb Program digital health intervention from Diabetes Digital Media. The intervention is used by over 300,000 people in 190 countries.*]

Background

Type 2 diabetes has serious health consequences including blindness, amputation, stroke, and dementia; and its annual global costs are more than $800 billion. Although typically considered a progressive, nonreversible disease, some researchers and clinicians now argue that type 2 diabetes may be effectively treated with a carbohydrate-reduced diet.

Although typically considered a progressive, nonreversible disease, some researchers and clinicians now argue that type 2 diabetes may be effectively treated with a carbohydrate-reduced diet, which could improve type 2 diabetes management and potentially even lead to remission.[168] Indeed, previous research with carbohydrate-reduced diets for type 2 diabetes do show improved outcomes (such as glycemic control, weight loss, and reductions in the use of hypoglycemic medications), for both very low-carbohydrate diets (roughly 20% or fewer of total dietary calories derived from carbohydrates)[169, 170, 171] or lower carbohydrate diets (roughly 40% or fewer of total dietary calories derived from carbohydrates).[172, 173] Although dietary interventions have historically been in person, online programs can be just as effective for some participants, as suggested by research that has examined diet and lifestyle interventions in adults with prediabetes.[174] Therefore, it is perhaps not surprising that the beneficial results of carbohydrate-reduced diets for people with type 2 diabetes (glycemic control, weight loss, and reductions in the use of hypoglycemic medications) have been replicated using online programs.[175, 176]

Objectives

Our objective was to evaluate the 1-year outcomes of a digitally delivered Low-Carb Program (LCP), a nutritionally focused, 10-session educational intervention for glycemic control and weight loss for adults with type 2 diabetes. The program reinforces carbohydrate restriction using behavioral techniques including goal setting, peer support, and behavioral self-monitoring.

Methods

The study used a quasi-experimental research design comprised of an open-label, single-arm, pre- and post-intervention using a sample of convenience. From adults with type 2 diabetes who had joined the program and had a complete baseline dataset, we randomly selected participants to be followed for 1 year (N = 1,000; mean age 56.1, SD 15.7, years; 59% [593/1,000] women; mean HbA1c 7.8, SD 2.1, %; mean body weight 89.6, SD 23.1, kg; taking an average of 1.2 diabetes medications).

The LCP is a completely automated, structured, 10-week health intervention for adults with type 2 diabetes. Participants are given access to nutrition-focused modules, with a new module available each week over the course of 10 weeks. The modules are designed to help participants gradually reduce their total carbohydrate intake to < 130 g per day to meet their self-selected goals. The program encourages participants to make behavior changes based on “Action Points” or behavior-change goals at the end of each module. These goals are supported with resources that are available to download including information sheets, recipes, and suggested food substitution ideas. The LCP online platform also includes digital tools for submitting self-monitoring and device-driven data on a number of different variables including blood glucose levels, blood pressure, mood, sleep, food intake, and body weight. Weekly automated feedback is provided to users based on their use of the program through e-mail notifications, and participants are notified when the next week’s module has been opened. Lessons are taught through videos, written content, or podcasts of varying lengths. The program stresses the importance of regular contact with the participants’ healthcare providers for adjustments in medications in weeks 1, 2, and 10. After the 10 weeks of modules have been opened, participants continue to have access to the education content as well as the ability to continue to track their health (glycemic control, weight). The content and strategies used in the program build off of prior research and theory. For example, evidence suggests that goal setting can act as an effective behavior change strategy used to improve adherence to lifestyle intervention programs in obesity management programs. The program therefore encourages participants to select a goal at the beginning of the program (such as to lose weight, reduce medication dependency, or make healthier choices for their whole family). Participants are also prompted to consider how their health would benefit from attaining their goal. Throughout the program, participants are periodically prompted to consider how close they are to attaining their goal. The program further reinforces behavior change through integrated tracking, whereby program users are encouraged to track their health data including mood, food intake, blood glucose levels, weight, sleep, and HbA1c. According to the control theory of behavior change, monitoring goal progress—that is, evaluating one’s ongoing performance relative to the standard—and responding accordingly is critical to goal attainment. Recent findings suggest that program interventions that elevate the frequency of progress monitoring are likely to induce behavior change.

Results

Of the 1,000 study participants, 708 (70.8%) individuals reported outcomes at 12 months, 672 (67.2%) completed at least 40% of the lessons, and 528 (52.8%) completed all lessons of the program. Of the 743 participants with a starting HbA1c at or above the type 2 diabetes threshold of 6.5%, 195 (26.2%) reduced their HbA1c to below the threshold while taking no glucose-lowering medications or just metformin. Of the participants who were taking at least one hypoglycemic medication at baseline, 40.4% (289/714) reduced one or more of these medications. Almost half (46.4%, 464/1,000) of all participants lost at least 5% of their body weight. Overall, glycemic control and weight loss improved, especially for participants who completed all 10 modules of the program. For example, participants with elevated baseline HbA1c ($\geq$ 7.5%) who engaged with all 10 weekly modules reduced their HbA1c from 9.2% to 7.1% ($P < .001$) and lost an average of 6.9% of their body weight ($P < .001$).

Observations

- The engagement platform used by patients for this study was only available on the Web and not as a mobile app. It would be expected that a mobile app would improve engagement.
- The criteria for inclusion within the project was the requirement to be over 18 and the ability to speak English.

- The percentage of individuals with an HbA1c level of < 6.5% increased from 26% (257/1,000) to 50% (503/1,000). This degree of control, when achieved through pharmacotherapy, is often accompanied by weight gain and risk for hypoglycemic events.[177] As the now famous Action to Control Cardiovascular Risk in Diabetes (ACCORD) study reported, intensive hypoglycemic medical therapy "increased mortality and did not significantly reduce major cardiovascular events."[178]
- A limitation was the rate of delivering the entire intervention, as only 528 (52.8%) completed all modules. However, a high rate (70.8%) reported 12-month outcomes. This could be due to the program being launched in November, with Christmas and seasonal activities affecting the rate of completion. On the other hand, given that this program was entirely automated and had a wide reach, a large number of individuals were able to complete the program.

Conclusions

Especially for participants who fully engage, an online program that teaches a carbohydrate-reduced diet to adults with type 2 diabetes can be effective for glycemic control, weight loss, and reducing hypoglycemic medications.

Case Study: Delivering A Scalable and Engaging Digital Therapy for Epilepsy

Charlotte Summers, Chief Operations Officer, Diabetes Digital Media, United Kingdom.

Background

Epilepsy is a neurological condition of brain. Different epilepsies are due to many different underlying causes. The causes can be complex, and sometimes hard to identify. A person might start having seizures because they have one or more of the following: a genetic tendency, structural changes in the brand, or genetic conditions. Epilepsy is sometimes referred to as a long-term condition, as people often live with it for many years, or for life. Although generally epilepsy cannot be "cured," for most people, seizures can be "controlled" (stopped) so that epilepsy has little or no impact on their lives. Treatment is often about managing seizures in the long term. Most people with epilepsy take antiepileptic drugs (AEDs) to stop their seizures from happening. However, there can be side effects with such medications, and there are other treatment options for people whose seizures are not controlled by AEDs, including the ketogenic diet.

Implementing the Evidence Base

The positive effects and therapeutic mechanisms of dietary ketosis and that of a ketogenic diet (KD) on human physiology have been well documented in literature. The KD is a high-fat, low carbohydrate (usually less than 50 g/day), adequate protein diet (Paoli et al. 2013), whose metabolic effects originates back in the 1960s; however the therapeutic effects of KDs can be traced back to the early 1920s when it was successfully used in the treatment of epilepsy (Kessler et al. 2011). Ever since, the potential clinical utility of KDs has been investigated by several studies, resulting in an accumulation of scientific evidence on the therapeutic role of KDs on various physiological disorders. Several studies have shown that the KD does reduce or prevent seizures in many children whose seizures could not be controlled by medications. Over half of children who go on the diet have at least a 50% reduction in the number of their seizures. Some children, usually 10–15%, even become seizure free. The Epilepsy Society support the KD as a treatment option for patients over 12 months old. Research highlights the therapeutic effects of the KD on patients with epilepsy as primarily reduced medication and reduced seizures. In a recent Cochrane systematic review of the evidence regarding the effects of KDs, Levy and Cooper found no randomized controlled trials (RCTs).

This demonstrates that epilepsy can be managed; and in some cases, patients can live seizure-free lives through the sustained application of a ketogenic way of eating. Through reducing sugar in the diet and at the same time improving blood glucose control, people with epilepsy can achieve significant health benefits such as reducing their risk of seizures and number of medications.

Sensor-Driven Digital Program

The Ketogenic Program for Epilepsy (KPE) is a structured education behavior change program for people with epilepsy. The KPE empowers users to sustainably adopt a lower carbohydrate lifestyle with the appropriate personalized education, health-tracking facilities, support, health mentoring, and resources to maintain a safe and sustainable lifestyle. As a result, people with epilepsy could expect to improve glycemic control and as a result reduce the incidence of seizures, reduce medication dependency, and improve confidence in managing their condition.

Health data is collected in real time through blood glucose monitoring, medication monitoring, and seizure tracking modules within the application. Unstructured data is particularly useful in understanding sentiment and the patient's psychology. Research activity will take place over the course of 12 months, reporting on 3-month, 6-month, 9-month, and then 1-year epidemiological health outcomes and engagement data followed by an 18-month and 2-year follow-up to demonstrate efficacy and adherence to the program over the short to medium term. This will be the world's largest and longest study on patients engaged with a digital platform epilepsy. It is possible that with the right funding this could be conducted as a randomized controlled diet, which would be the world's first in KDs delivered for epilepsy through a digital platform.

Research

As part of this project, we seek to learn the most efficient and effective methods to implement and accelerate at-scale delivery of our technology to the UK's NHS population and international bill payers. The project is led by an award-winning and experienced team, recognized for innovating digital health, who are determined to revolutionize the health and well-being of people across the globe. The technological challenge is to create a scalable, engaging, and effective solution for global implementation. This challenge is mitigated through the project extending on the infrastructure of DDM's (Diabetes Digital Media) Low Carb Program for type 2 diabetes, with clinically validated outcomes and 71% retention at 1 year. Surprisingly, out of 300,000 patients globally registered within the Low Carb Program for type 2 diabetes, there are 3,112 people with epilepsy (0.5% of the UK population)—showing the readiness for an online, nutrition-focused intervention for this population.

DDM intends to conduct the world's first RCT on patients following a ketogenic protocol with the Ketogenic Program pioneering in the space of digital health innovation. The potential cost-saving impact to the NHS is significant. Patients who are empowered and have improved health and well-being are also more active members of their communities and have lower social care needs.

Project Impact

The greatest impact will be felt by patients with epilepsy and their families through empowering patients to manage their epilepsy. Evidence demonstrates that a KD in people with epilepsy can be maintained by infants and adults with improvements in number of seizures and medication consumed. Evidence also demonstrates positive effects on cardiovascular disease risk. The health improvements and potential cost savings are sizeable. In addition to this, the project is of tremendous value to the UK economy and the NHS, with reduced complications, improved mental and emotional health, reduced hospital admissions, and reduced medication having a direct impact on the budget of the UK Treasury.

Positive social impacts experienced by the patient have a repercussion for wider communities, businesses, and the UK economy. As the result of improved patient and population health, organizations will benefit from fewer sick days and reduced absenteeism, improved mental health and improved perceived quality of life, as well as a reduction in the perceived burden of managing epilepsy. The positive impact is also received by the clinical healthcare community—through reducing physician and healthcare professional burden and enhancing the evidence base.

Preliminary Analysis

The objective of the research arm of this project is to evaluate the 1-year outcomes of a digitally delivered Ketogenic Program: a nutritionally focused, 16-session educational intervention for epilepsy control through provision of a KD. The program assists in patients placing themselves in ketosis using behavioral techniques including goal setting, peer support, and behavioral self-monitoring. Interesting correlations between elevated blood glucose and mood enabled predictive algorithms to be developed to identify symptoms of impending seizures, alerting patients through notifications to take action. Especially for participants who fully engage, an online program that teaches a carbohydrate-reduced diet to adults with epilepsy can be effective for glycemic control, weight loss, and reducing medication and the number of patient seizures. An RCT is required to understand the clinical impact of such a digital therapeutic.

Case Study: Improving Learning Outcomes For Junior Doctors Through the Novel Use of Augmented and Virtual Reality

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Background

Junior doctors arrive at a university eager to help mankind, yet often they are unaware of how to deal with high-pressure, critical scenarios. Dealing with medical concerns appropriately—whether emergencies or not—requires years of experience and learning. Over time, exposure in doctor surgeries, hospitals, and clinics develops the self-assurance, readiness, and experience required for junior doctors to realize their vocation. High-pressure scenarios, such as a patient having a cardiac arrest, require pinpoint precision accuracy in decision-making and actions. For some time after first arrival to a university, junior doctors are not ready to make such decisions. This is where augmented and virtual reality provides an opportunity to engage students in learning that readies them for life as a doctor. What's more, with 1,500 students in any one year, group trips to hospitals are expensive and logistically difficult to manage.

The project was recognized for its pioneering nature in 2016, when it won an Association for the Study of Medical Education (ASME) Education Innovation Award.

Aims

The aims of the project were manyfold:

- Increase the exposure to simulation and training environments for junior doctors without the use of simulation centers.
- Give inexperienced doctors the experience they require in a noncritical environment.
- Demonstrate effective and ineffective clinical practice.
- Encourage students to consider their own practices and thought processes.
- Immerse students in a clinical learning environment and identify whether the use of virtual reality enabled them to become familiar with the healthcare setting, patient unpredictability, and provided the confidence to cope with high-pressure scenarios.

Project Description

It was agreed that the project have as wide a reach as possible. This eliminated virtual reality hardware such as the HoloLens or Oculus and focused the delivery onto mobile devices. The Samsung Gear and Google Pixel were able to handle the delivery of the content with the use of a headset to extend the view into virtual reality. This was logical considering almost every student owns a phone, whereas the use of HoloLens and Oculus is still relatively niche.

Simulations of a variety of clinical experiences were filmed with 360-degree videography using both doctors and patients as actors. These simulations were short 5- to 10-minute videos that featured decision moments where students needed to make an active choice—including a patient suffering from cardiac arrest and a patient with schizophrenia becoming hysterical. These videos were integrated into a virtual reality application that enabled students to explore a clinical setting in virtual reality, engage in the environment, and encouraged them to make a variety of decisions during the process.

Conclusions

- Virtual reality simulation provided a prime and safe clinical environment for junior doctors to explore their practice.
- In particular, the technology allowed students to focus on mistakes—unifying approaches to medicine across the cohort.
- The technology enabled students to learn anywhere, anytime: at home, school, or library.
- Virtual reality simulations were accessible by all medical students with the appropriate hardware.
- Students were able to become more active in decision-making in lectures.
- The virtual reality experience encouraged discussion and learning.

- It was cheaper and logistically easier to manage than student trips to hospital wards.
- The use of this innovative technology prepares junior doctors for the demands of the vocation.
- Research and exploration into the appropriate pedagogies to support virtual reality learning is required as the tools become more freely available.

Case Study: Big Data, Big Impact, Big Ethics: Diagnosing Disease Risk from Patient Data

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Background

The variety and velocity of patient data has exponentially increased over recent decades. This data has not progressed the robustness of decision-making. This leads to questions as to why decision-making is not becoming more data-driven and what can be done to validate and expedite its adoption.

Diabetes.co.uk is the world's largest diabetes community, based at the University of Warwick, and the platform welcomes over 45 million visitors a year. As the world's diabetes community, the organization provides a range of services that focus on the patient-data ecosystem to empower patients to manage and control their health. By collecting patient data, or real-world evidence, over time, the ecosystem is created such that it offers insights, education, and feedback on particular aspects of the patient's health.

Platform Services

The platform collects a wealth of data. From the moment of platform access, behavioral and engagement metrics are collected, with patients progressing onto registering for the platform, opting in to part with over 120 variables that cover their diabetes and overall health status. Once inside the platform, a variety of data types are collected—unstructured data in the form of conversations, interactions, engagements, and behavior; and structured data in the form of self-reported, device-driven, wearable, IoT, and clinical health record data. The platform provides a number of services to patients and bill payers.

Medication Adherence, Efficacy and Burden

Medication adherence, adverse effects, and wastage are concerns that pharmacology seeks to overcome. Patients with diabetes are typically on at least one medication on entry to the platform. Within the platform, patients evaluate their medications at regular intervals, sharing their own opinions on the use of medicine in the real-world, and report more structured data such as side effects, adherence, efficacy, and burden of using medications. This data is mapped geographically, by condition, medication, and other markers and fed back in a de-identified, aggregate manner to pharmacological and academic partners for research purposes. Data is used by partners to identify new drugs and understand interactions, usage, adherence, and real-world adverse effect prevalence. The same data is also used to improve patient safety. For instance, the platform alerts members on particular medications or using particular devices should there be an issue or recall.

Community Forum

The Diabetes.co.uk community forum is the world's largest support community for people with diabetes and provides an unrivalled insight into the global diabetes population. The platform welcomes people with all types of diabetes, carers, and healthcare professionals. The concept is simple: real people with diabetes talking about their own experiences and speaking to others who are in a similar position. Patient engagement is high; there is over 2 million years of cumulative experience among members, who spend over 17 minutes each visit on the platform. As one on the world's most novel digital communities, data and respective insights from the online forum and dissemination of academic findings are constantly shared with our patient-support network, medical advisory board, partners, and other interested networks.

A first phase study by Royal Holloway, University of London, in 2017 investigated the role of online health communities in patient self-management, assessing the following:

- How patients appraise knowledge from online health communities in managing diabetes; and
- How a patient's healthcare professionals perceive and can potentially use such knowledge to innovate their clinical practice.

The study concluded the following:

1. The Diabetes.co.uk forum is a catalyst of innovation.
2. The Diabetes.co.uk forum empowers patients, meaning
    i. A good relationship with their healthcare professional
    ii. High confidence or self-efficacy in managing their condition
    iii. Feeling less emotionally burdened

This was supported with data from 13,000 patients who highlighted the patient benefit through platform usage:

- 53% improved blood glucose control
- 58% improved quality of life
- 59% improved confidence in managing diabetes
- 65% improved dietary choices
- 76% improved understanding of diabetes

AI prioritization of patient interactions

To meet regulatory requirements, any health platform must report patient health or safety concerns immediately on discovery. This would prove cumbersome for a developed health platform such as Diabetes.co.uk if completely human-led for several reasons:

- Monitoring of medical discussion groups and interactions requires human-intensive staffing to spot concerns for regulation purposes.
- Lots of time is wasted if humans were to do all the checking.

It was decided that to meet our obligations, the use of AI bots would speed up the process, enabling humans to spend time with the concerns that matter. This was realized through the development of a neural network-based classifier to determine sentiment and concern based on contents, user profiles, and frequency of other key metrics. The classification system went through several hundred rounds of validation, taking a subset of the huge data lake that was available from the millions of posts. The classifier was able to spot 99.8% of all concerns, with humans required to intervene in 0.2% of cases. There were a number of benefits to the AI prioritization:

- It saved a considerable amount of human time.
- Human time was spent on the problems that were of most concern.
- The flagging of discussions occurred in near real time rather than the 15–20 minutes it would take a human to do so.

This information also assisted the customer support teams to efficiently deal with user queries by knowing exactly what a conversation was about, typical responses to such a query, and what to say to a user to ensure a favorable outcome for all parties involved. Additionally, by gauging the sentiment of users and storing it, user data can be implemented to build additional systems in the future.

Real-World Evidence

Through the analysis of patient data, we can determine a discrepancy between official and real-world health statistics. For instance, 14% of people with diabetes in the United Kingdom are expected to have a mental or emotional health concern, whereby the platform sees 44% of users with this health condition. This highlights that further exploration and understanding of the patient population is severely needed to ensure critical aspects of patient care are not neglected. Interestingly, partners have become more interested in real-world evidence as the years have progressed, partially to do with concerns over research funding and conflicts of interest.

Ethical Implications of Predictive Analytics

Predictive analytics enables intelligent classifiers to predict the risk of disease. The collection of a varied patient dataset—including conversations, health markers, demographics, and behavior—enables the development of a sophisticated model that can be used to refine predictions further. One of the unintended consequences of the project was discovered when deploying an AI model that predicted the risk of a patient having pancreatic cancer. Pancreatic cancer typically effects 1 in 10,000 people and is frequently misdiagnosed. Often, patients receive a diagnosis when it's too late. A pancreatic cancer AI model was developed using a clinical dataset of health metrics, engagement, and behavior data and first predicted the likelihood of poor patient metabolic health. Should patients meet the threshold for poor metabolic health, the model evaluates the risk of the patient having pancreatic cancer.

Communicating this information to users was a first-time problem for the organization. All relevant stakeholders, including all members of the Medical Advisory Panel, were prompted for their input on this topic. Predictive analytics had previously been used to inform patients of possible hypertension or increased risk of conditions based on lifestyle. However, informing patients of their risk of pancreatic cancer was considered to be unethical, particularly as we did not want to create additional mental health concerns or anxieties.

How should a user be told of a possible life-changing concern? The key action for this communication is to nudge the patient to see their doctor or physician as soon as possible. The factor for success in this case was determined to be user friction. The less friction there is between the user and communicating party, the more successful the engagement. Stakeholders from behavioral economics were vital in testing and confirming an engaging communication to inform the user that their data fell outside expected norms without raising fear. To do this, the prediction was framed against patient and population demographic and medical data. Rather than being told they were the only patient to see anomalous data, patients were reassured that others have also seen similar patterns and been successful in improving their health.

Integration of the IoT

Sensors in wearables such as accelerometers, altimeters, and heart rate and skin temperature monitors provide a tremendous amount of useful information. For instance, motion, sweat molecules, and conversations are all useful and relevant data points. Such metrics can be used to take a snapshot of metabolic health, cardiovascular health, and mental health. For this to be conducted at scale, there must be little to no friction between the patient and providing parties. The less friction there is between the user and whom they choose to share data with, the more successful the product. Wearables are becoming increasingly used in incentivized wellness propositions. Validating patient behaviors and general physiology facilitates the personalization of premiums and outcomes-based reimbursements.

Patients have the option to connect their devices and applications to the Diabetes.co.uk architecture. What is interesting is that younger users typically adhere to wearable usage and find it easy, while elderly users typically did not. This is of relevance to insurance and incentivized wellness propositions, as most claims come from older policyholders.

Conclusions

The realization of precision medicine is not without technical and ethical challenges. IoT and conversational and wearable data are just examples of a variety of data that can be collected and used to empower patients in real time, facilitating improvements in health and well-being. However, with data and the application of AI, come ethical concerns, particularly in the prediction of future disease risk. The lack of processes and governance on such topics is urgently required as the abilities of AI mature.