CHAPTER

14

Disruptive technologies: Present and future

Magdala de Araújo Novaes[a], *Arindam Basu*[b]

[a]Telehealth Center, Clinics Hospital, Medical Science Center, Federal University of Pernambuco, Recife, Brazil, [b]School of Health Sciences, University of Canterbury, Christchurch, New Zealand

Introduction

Arindam Basu

Telehomecare, or telehealth applications in home-based care, seeks to offer new strategies to improve and expand access to care, using a range of distance-based digital practices. Such care may be associated with health promotion, prevention, and treatment of chronic diseases, for critically ill patients (acute or terminal) or for home-based rehabilitation. While home care is increasingly dependent on face-to-face interaction with humans (be it in real life or virtual spaces), it is a fact of life that robots and automation have replaced human workers in many fields and are threatening jobs everywhere. While the health sector has been a late entrant in IT, such replacement, so far, has been little, but that may not be true in the future. The pros and cons of the **use of robots** where handiwork is involved, that is, surgery is a high-impact topic worth studying. Tied to the concept of robotics is the concept of **artificial intelligence (AI)**—a field of computer science with high overlap of statistics and mathematics and can be called machine learning, which has advanced further to deep learning that the machines learn themselves. The role of AI in improving healthcare especially in underserved areas is being noted by international agencies like WHO. ISO as well as ITU.[578] **Virtual reality (VR)** is considered revolutionary within healthcare, due to new possibilities offered for interfacing (system/user); the use of multisensory devices; navigation in three-dimensional spaces; immersion in the context of the application;

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sharing and interaction in real time; and extending the senses that previously were simple vision and hearing to three-dimensional manipulation using touch, pressure, and even smell enabled through the use of devices such as head-mounted displays (HMDs), gloves, or the user's own body. Last but not least, **blockchain** refers to a public decentralized ledger, where the valid peer-to-peer transactions are recorded in a distributed chain of blocks, with constant updation as long as some new approved transactions take place.[5] As soon as a block is appended to the blockchain, the update is transmitted to entire distributed structure, providing redundancy, transparency, and security.

Telehomecare

Magdala de Araújo Novaes

Overview

Telehomecare, or telehealth applications in home-based care, seeks to offer new strategies to improve and expand access to care, using a range of distance-based digital practices. Home care is characterized by the delivery of health services to the patient at home. Care may be associated with health promotion, prevention, and treatment of chronic diseases, for critically ill patients (acute or terminal) or for home-based rehabilitation. We will discuss here telehomecare by the home health agencies that provide health services to patients in their homes as an alternative to traditional hospitalization.

Concepts and applications

Home care is one of the fastest growing modalities in the world. By 2014 the number of home-based care agencies increased by 66%, and more than 4.9 million patients received healthcare from 12,400 HomeCare agencies between 2013 and 2014. More than half of the care assisted by these agencies was for continuation of care after hospitalization. With an aging population, the number of patients receiving home healthcare will increase, making HHC a major source of intensive care with concomitant lowering of hospital readmission.[476]

The prominence of home care emerged in the post WWII period of the 20th century as a palliative care strategy, to minimize infection risks and to reduce hospitalization costs. Its recent rapid growth can be partly explained by the rising health needs of an aging population with emergence of a rising number of persons with multiple chronic problems like cancer, COPD, and Alzheimer. With the transition of care from the hospital to home, the patient continues to receive care by a multidisciplinary team but at a place that allows greater comfort and contact with the family, often contributing to better treatment results.

The attending physician devises the home care plan for the patient, based on the patient's clinical profile. There is a need to take a comprehensive view of necessary infrastructure in place and coordination between the health team—physician, nurse, physiotherapist, nutritionist, social worker, and family members—who will provide care on a 24/7 or on a predefined support scale (Fig. 1). This scenario of geographically distributed care is very conducive to the insertion of distance health practices (telehealth), which in this context contribute to improve the performance of home care and enabling a less invasive and more personalized care.

Imagine a patient with advanced heart failure, renal failure, and motor weakness, with frequent calls for emergency services and several hospital admissions in 1 year. This patient is offered palliative care and is assigned to a HomeCare program. The healthcare team develops a specialized treatment plan tailored to the patient's needs. Nurses and physicians would come to the home through scheduled visits, conduct face-to-face assessments, and deliver instructions for the patient and family members regarding use of devices for collecting health information including vital signs and sending data via the internet to the facility. The information collected at home is grouped in an electronic health record (EHR), which is constantly accessed by the professionals involved. As a result the patient can possibly reduce the number of hospitalizations and emergency calls by 60% during the same period of time.

This is an example of 24-h home care that allows reflection on the scope, impact, and effectiveness of home care, showing positive results related to the improvement or nonaggravation of patients' health status. This is a situation where telehealth sensors and networked devices have enabled real-time clinical evaluation of patient(s) and continuous monitoring of their health parameters and consequently allow agile decision-making.

FIG. 1 Nursing care in the home. From Interne Home Care. (www.interne.com.br).

In telehomecare, alert systems located in the home of the patients send notifications to a telemonitoring center after collecting data on specific symptoms and signs of the patients at home. In the telemonitoring center, nurses and doctors analyze data in real time and deliver interventions aimed at avoiding complications or prevention of worsening of the health state of the patients. Messages can be transmitted over the phone or using other applications, directing specific behaviors to the patient's family members who are their carers at home or to the care team itself. Visits by physicians and supervising nurses may be performed from a distance, over and above scheduled appointments, thus improving patient safety. In addition, the use of an electronic patient record, coupled with applications and online interaction systems (chat or video calls), allows simultaneous access and hence engagement by all professionals involved.

Telehomecare can be applied in different scenarios, but they are especially suited in the setting of patients with chronic obstructive pulmonary disease, patients with heart and renal failure, those with NCDs, and the aged.

Results of supplementing traditional care with telehomecare are encouraging. Sahakyan et al.[477] analyzed data from 3513 patients in a telehealth program, 62% of whom had heart failure, 55% had COPD, and 29% had diabetes. Home care was associated with a significant reduction in the blood pressure levels of the patients monitored in the telehomecare program, with more pronounced alterations in patients with uncontrolled blood pressure.

Applications, websites, or online interactive systems can be used in home health monitoring. Jeffs et al.[478] have developed an application for home healthcare and have evaluated the usability, acceptability, and scalability of this application. Their application software allows monitoring of health status and has a patient-oriented user interface for loading information.

Impact and future trends

Home healthcare, administered either on-site or remotely, allows specialized care, which focuses on the patient and his particular needs, with benefits of reduced hospitalizations and consequent cost saving. The positive impact is perceivable both from an institutional perspective and the healthcare system in general. Laustbader et al.[479] has reported the impact of a palliative care program at home and reported that a $10,435 reduction for patients who received home care assistance compared with those who received traditional hospital care. In addition, the cost per patient during the last 3 months of life has been $12,000 lower.

The impacts of home care are even greater in the health system when associated with the use of wearable devices. Here the patient wears sensors that collect health parameters viewable on smartphones or in the monitoring centers. It is a worldwide trend related to the strong growth of mobile technologies around the world. Patients can, for example, see their heart rates in real time, or the patient's family can monitor the patient's location in case of mental illness. With such devices, it is possible for larger hospital equipment and numerous monitoring devices to be dispensed with.[480] An example of a prophylactic wearable is the Spire device, which is attached to the patient's garment by a clip; the sensor identifies changes in the user's breath and sends a notification to their smartphone.[481]

The potential to reduce health spending from the home care and use of these technologies has already been discussed, with possible reduction of the need for periodic reassessments and frequent medical consults: physicians monitor the data, and the patient requests an on-site visit only when some abnormality has been identified.[481]

Despite the great benefits brought by telehomecare, there are challenges to be overcome, such as the adequate training of professionals and the development of systems that ensure greater patient safety, which evaluate not only isolated symptoms but also a wider range of health aspects, as well as adapting to the local infrastructure where the patient is located.[482] False alarms constitute a major chunk.

The applications of telehomecare are expected to expand particularly in developing countries where traditional services are limited and potential of hospital-induced infections is high. Clear guidelines and protocols ensuring quality of care, are needed, along with training, and guidance of the professionals involved to make telehomecare increasingly effective when it is presented as an alternative or as a supplement to traditional care.

Tele-robotics in healthcare including in surgery

Shashi Gogia

The 2008 movie *WALL-E* (https://en.wikipedia.org/wiki/WALL-E) highlighted a possible redundancy of human hands or feet in the robotic era, with retention of only the brain and eating capability. Interestingly, however, IT was conceived more to emulate and replace brain functions.

Robots and automation have replaced human workers in many fields and are threatening jobs everywhere. Since the health sector has been a late entrant in IT, such replacement has so far been little, but may not be so in the future. This subchapter discusses the pros and cons of the use of robots where handiwork is involved, that is, surgery.

We start, however, by briefly describing an entirely different set of telepresence robots that are more general, not any specific procedure related. The first is a static bedside robot that provides emotional care for patients. The second wheel-mounted one offers teleconsultations especially for the ED, OPD, and inside the ICU where patients can be prescribed streptokinase and other relevant medications after remote physical examination by cardiologists and neurologists[483] within the golden period after ensuring confidence of the diagnosis. These so-called point-of-care (PoC) robots have been found to extremely beneficial as per a recent review from Korea.[484]

"Big surgeons make big incisions" was an adage of yore. In those days a generous incision allowed the surgeon flexibility to safely complete a delicate dissection and manipulation through a complete view. It ensured that crucial structures were left unharmed even while stopping inadvertent bleeding. Prolonged postoperative pain was felt to be an acceptable consequence. What is called minimally invasive surgery (MAS) is essentially working towards conservative skin incisions, manipulation, and dissection being restricted to only those tissues that need to be removed or repaired. The term was introduced when manipulation was added to stereotactic access and to endoscopy of all possible body orifices (nose, mouth, rectum, and urethra) and of body cavities, that is, laproscopes, thoracoscopes, arthroscopes, etc. The benefits of pain reduction even lead to an artificial manipulation space being created (retroperitoneal for kidney, extra peritoneal for hernia, Carpal tunnel, face, etc.) or use an existing albeit, pathological one—the hydronephrotic kidney.

Surgery is a highly skilled technique requiring brain and hand coordination. One may have an inclination to learn the skills, but no further DNA exists that one can be a borne surgeon. Even the famous YouTube video about a 7-year-old boy performing surgery in a village described him using a book for reference! (https://www.youtube.com/watch?v=23wuWZWgC5U).

> It takes 5 years to learn when, why, and how to do a surgical procedure, another 10 years to learn **when not to do** the procedure. ***(Anonymous)***

Basic procedure techniques like tissue handling, ensuring the lack of tension, and knot tying are general skills that one learns over time. With the introduction of newer techniques especially MAS, the entire scene changed. Many additional skills needed to be imbibed like manipulating the scope to zoom and catching a bleeder even while looking at the screen etc. Use of lasers to coagulate the gall bladder bed had a short tenure but complications including inadvertent perforations by instruments not under vision persisted. Complication rates reached an all-time high during the 1990s.[485]

Even if basic and extra skills are imbibed, there are additional issues that automation can correct. A surgeon could be tired, sick, or simply unavailable when the need arises due to a multitude of reasons. Manipulating instruments and even their steady holding for long periods is tiring, which becomes less ergonomic when doing endoscopy. Endoscopic manipulation is done in all directions, but visualization is in 2D, and mostly, the person moving the camera is someone else. Working with a new or different assistant has additional issues. Finally, doing the same job day in day out is boring.

Computers and robots do not get fatigued, never get bored, can configure multiple levers (hands), and coordinate many different visions. Configuring, interestingly, is extremely easy if the task is unvarying and repetitive. Robots are preferred for activities that are repetitive, can be dangerous for the user (e.g., danger of radiation), or need access to difficult-to-reach spots. The automotive sector, the leader in robotics, uses it, for example, for material handling, spot welding, and painting. Bomb disposal squads were among other first-level users.

Added advantages that make robotics score higher than humans include a possibility of 360* vision; auto zoom; special sensors, for example, temperature; color filters that can distinguish a cancer cell from normal, multiple attachments; and most importantly quick coordination between all these. However, getting all this together is a slow learning process and expensive. One also has to consider that any mishap can be a life-and-death issue with little clarity on whom to fix responsibility for the said mishap—see the separated positions between the patient and surgeon in Fig. 2. In an actual scenario the distance can be much more—even across the globe.

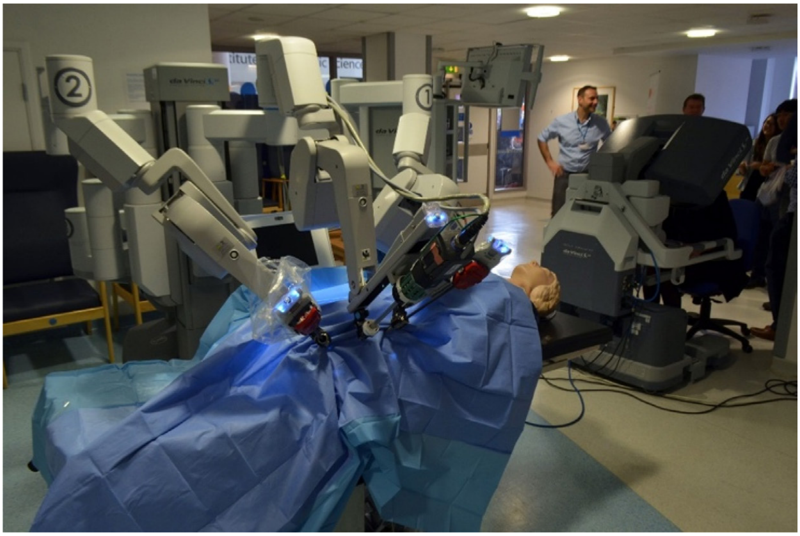

FIG. 2 The Da Vinci Robot operating on a dummy while the surgeon is sitting in the right side.By Cmglee—Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=39154360.

On the other hand, once the software and skills are embedded and fine-tuned, there is no need for any extra training or effort. Replication is a cinch and can be done to an unimaginable scale that also brings down costs.

Initial skill acquisition by such IT systems has to be an amalgamation of many minds—computer engineers, surgeons, anatomists, etc. Each advance requires testing, learning, and coordination. Surgeons have to be trained to utilize the robotic system, including taking over after recognizing when and where system is failing. Changes have to be incremental.[a] But these are early days yet. Automation is not yet complete and needs supervision by humans, who, in turn, needs to be trained on the particular machine so that the supervision is effective. As of now, robots show significant promise, but robust evidence base supporting its use remains lacking.[486]

Robotics is expensive. Still, it has become routine in many surgical fields especially if there are endoscopic procedures that require remote manipulation. Hard-to-access areas needing standardized but repetitive action top the list. Examples are prostatectomy, neurosurgery, cardiac surgery, and vascular surgery. Telepresence also permits telementoring of novice surgeons. Joint implants are a special case as each newer implant has very precise anatomic specifications but would require high level retraining of the surgeon. Training a robot is a onetime replicable affair.

Laparoscopic and thoracoscopic procedures have some constraints, and robotics has been an attempt to correct them. These were a need for a stable camera platform with flexibility of zoom and broader field of vision; conversion of the two-dimensional view into something that allowed depth appreciation; stability of the holding and retracting instruments—that is, inserted from the third and fourth ports; and finally a need for better ergonomics of not only single-handed laparoscopic instruments but also a comfortable, sitting operating position.

The first operating robot was a voice-activated AESOP. It was funded by NASA to help service its space shuttle while in orbit. It was cleared, by the FDA in 1994, for use as a surgical assistant, maneuvering the endoscopic camera while the surgeon was controlling other instruments, essentially replacing the cameraperson to facilitate solo-surgeon laparoscopic operations.

Movements though slow and expected to improve over time, were very precise, nonjerky, and without any tremor. Response time for the rare mishap, given the precision movement, was in nanoseconds as opposed to milliseconds in humans.

[a]Read the section comparing evolutionary and revolutionary changes in Chapter 1.

This further extended to taking charge of other instruments and coordination and resulted in what was now called ZEUS. After animal testing, ZEUS carried out a tubal reanastomosis in 1998 and later a coronary artery bypass surgery (CABG). The daVinci Robotic system came up separately, but both have now been merged.

The daVinci system has been found successful for almost all types of laparoscopic procedures. However, a special role is mentioned only for a few select procedures like hysterectomy, transoral and velopharyngeal surgery in the head and neck,[487] radical and sometimes even standard transurethral prostatectomy (TURP), and CABG; besides some other conditions that mean prolonged surgery; and other hard-to-reach areas as explained earlier. For most procedures, however, currently, the expense is unjustified. Also, there is a cost on training on using daVinci itself, and the complication rate has not really decreased.

RoboDoc is another one that came up for orthopedic surgery, specifically total hip and now knee arthroplasty. It is in widespread use outside of the United States as it has yet not received FDA clearance.

Neurosurgery

Neurological surgery is well suited for the incorporation of robotic assistance. Bony superstructure meant small holes for manipulation—spurring a growth in stereotactic surgery. This minimally invasive neurosurgery became possible once CT scans allowed for pinpoint localization of lesions. That one had to work between tight anatomical confines, and large veins were a further incentive along with understanding of potential harm related to even the slightest mishap. Even nonstereotactic, procedures are microsurgical in nature. However, the many and varied steps involved in localization, access, and surgical execution would require distinct "robotic competencies." The CyberKnife is an image-guided robotic technology for noninvasive cancer surgery to provide radiosurgery (e.g., a gamma knife uses gamma rays) for lesions anywhere in the body when radiation treatment is indicated. It has a special role for hard-to-reach brain tumors like meningiomas of the skull base.

Safety aspects

Auto-driven cars have killed people,[488] the 2018 Lion Air Crash in Indonesia[489] killed 189 people. It was due to two separate flight automation control systems working against each other—the pilot was not even aware of the problem or the solution, which was to simply switch off the computer! One hundred forty-four deaths in the United States have been linked to robotic surgery.[490] An inquest after a botched surgery death in

Newcastle, England, revealed how the robot first made a wrong stitch during a mitral valve replacement procedure—but additional stitches to correct the same made matters worse. At one stage, there was so much blood clogging the camera that the controlling surgeon could not see anything. Action has been taken against the surgeon.[491]

The biggest issue is fixing responsibility for such unwarranted deaths. In the case of the Lion Air Flight, the Boeing company has been sued as the pilot also died. Such an end, fortunately or unfortunately, is unlikely during a surgical procedure unless the surgeon gets a heart attack horrified at the turn of events!

In conclusion, there is a possibility that robots may better the surgeon in the future, but there is need for caution. Complications have occurred and may rise further. Even if it is, hopefully, far less than the cases of medical negligence we face today, the issue of fixing responsibility will be extremely complex.

Artificial intelligence and IoT in healthcare

Abhishek Gattani

What is AI?

The term intelligence has very diverse meanings including spying! For our purposes, it can be a form of deductive reasoning or a method of "communicating complex ideas, acting on them, and holding conversations."[492] Narrowing this broad concept of the purposes of computation and telehealth, it also can be a form of reasoning or critical thinking.

Artificial intelligence (AI) is a field of computer science with high overlap of statistics and mathematics and can be called machine learning. AI is a broad term and often misunderstood.

AI's history and evolution

Birth of AI happened in the 1940s and 1950s with its winners and setbacks.[493,494] Notable successes in the health domain[b] included MYCIN,[78] ePrescriptions, and CDSS especially using Arden Syntax.[79] A big change since 2011 has been the advent of deep learning leading to exponential growth. AI is being described as the new electricity and data the new oil. Companies like Google, Apple, Amazon, and Facebook are investing heavily in AI labs. So have the governments of China, the United States, and Europe—in hundreds of billions of dollars to ensure that they do not

[b]These are discussed in Chapter 5.

lag behind economically and also sadly militarily. The tools of warfare are changing to precision kills![495]

What is deep learning

Logic is the basis of programming within computer systems. A simple If/Then/Else example**—IF** (the drawn object having four lines and perpendicular margins) **all lines are equal, THEN** (it is a) **Square** (, or) **ELSE** (it is a) **Rectangle.** There are many variations that are largely mathematical in nature and depend on calculations. Now, let us take this logic further into machine learning. A cube or a rectangular block has six sides; out of them, only three can be visible. And even among these entities, it is unlikely that their rectangular representation, a 2D figure, will have appropriate angles or sizes of the lines. With machine learning, nevertheless, accurate measurement can be made available for the visible lines and angles—also extrapolated for invisible ones to surmise a cube, cuboid, irregularity, etc. CT scans are that way reconstructs of multiple 2D images in a different plane or in 3D.

Deep learning goes beyond such reconstructs. It literally self-learns from conclusions, and uses them for further analysis, which means using data and the surmises, that is, outcomes of a clutch of data to further create the association and reasoning used to create a certain predictivity. Unlike machine learning where all the inputs are manual, deep learning takes in existing inputs and hence depends on much higher volumes of data. In machine learning and deep learning, the accuracy and sanctity of data are important though deep learning is somewhat more flexible.

A good way to describe AI would be its similarity to a child. A child's learning comes by regular associations between pictures and moving objects like a dog, cat, or table. Then, over time, children develop patterns and can recognize these objects on their own. AI works similarly; essentially, it is a class of computer programs that can learn patterns from data. The contention is that computers, in the domain of artificial intelligence, can serve as "intelligent agents" mimicking if not matching humans in thought processes and reasonings; it is possible for computers to emulate human cognitive behavior. Such cognitive performance systems would eventually be closer to the notion of human "intelligence."[496]

Just like a parents' understanding that quality education (kind of school, teachers, books, etc.) helps long-term career building, AI systems also need emphasis and detail on the quality of training, as well as the training methodology (kind of data, kind of labels, frequency of these examples, etc.). In a sense, AI is quite different from traditional software. In traditional software, engineers write algorithms, logic, heuristics, and patterns to convert data and information towards knowledge and wisdom. Today's AI instead tries to derive wisdom by ascertaining patterns within the data that are fed in. What makes it interesting and super capable is its close coordination with the internet to capture more data as per need and hence the relevance here to describe Internet of Things or IoT in the same chapter. Alexa and Google Home are good examples. One of the initial responses from them are "I am still learning" as it starts analyzing the voices of its masters and also their favorite objects and searches.

"Intelligence is largely determined by genetics. Critical thinking, though, can improve with training and the benefits have been shown to persist over time. Anyone can improve their critical thinking skills. Doing so, we can say with certainty, is a smart thing to do."[496] A deep learning model is designed to continually analyze data with a logic structure similar to how a human would draw conclusions.

Why the hype?

To understand why this sudden surge in AI research, funding, and applications, let us take AI application in telemedicine as an example, that is, skin-lesion recognition. The idea is to be able to use a mobile phone camera to screen for various blisters, macule, melanoma, etc. For years the steps of building such an application included collecting lots of images of various lesions, writing computer programs to extract features from those images, and using machine learning to learn how these features combine for a lesion type. Vaguely speaking, AI will learn that, if for the lesion (A) asymmetry is high, (B) border is irregular, (C) diameter is greater than 6 mm, and (D) it is pigmented, then most likely the image is of a melanoma.

Note that writing good detectors for all the earlier features (pigment, asymmetry, etc.) is essential and took years of research. Not only is feature engineering expensive, but also it takes years of work to get good accuracy with human engineered features. With deep learning, feature engineering is learnt from the images. This dramatically reduces the years of R&D needed for an AI application and also results in higher accuracy. Deep learning systems have consistently beaten the state-of-the-art results in various domains like face recognition, OCR, and speech recognition (see Fig. 3).

AI scores greatly over human learning in many ways. Even while a computer without electricity is dead and without information, it gets access to information at nanospeeds when it is switched on. The memory resource is billions of computers and other devices worldwide. Hence, learning never has to go through the cycle of birth, schooling, readjustment, failure, and death. What one device learns can be replicated instantly. Transfer between individuals has to be either relearning or through genes that can take generations! No need for DNA or reverse transcriptase. The initial learning is slow and laborious. Unlike humans, there is no feedback or

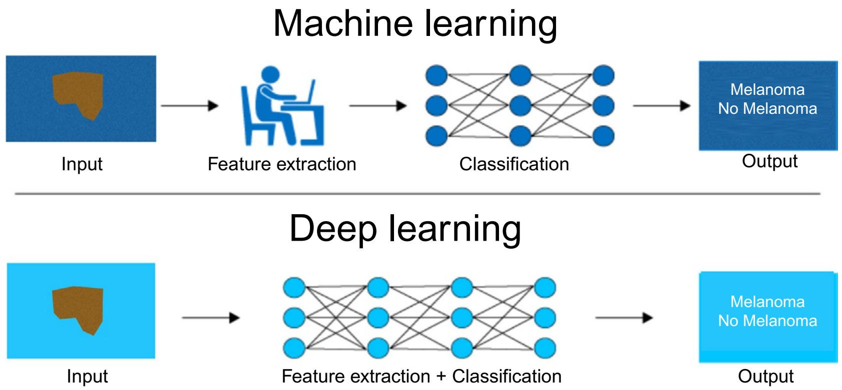

FIG. 3 Feature extraction is done by machines themselves in deep learning.

even penalty on how effective or harmful it will be. That will be and always remain to be a slow manual process.

Applications of AI in healthcare

Because of the dramatic increase in the amount of data, increase in computing power, and reduction of costs in building an AI system, deep learning-based AI is finding many new applications in healthcare. Here are a few examples:

Diagnosing diseases: AI systems can learn to see patterns similar to the way doctors see them. Examples of such systems are many: breast cancer cell segmentation from pathology images (Fig. 4A and B), malignant lymphoma classification from biopsies, and pancreas segmentation from CT scans (Fig. 4C). To train these systems, one requires high-quality labeled data. Currently, one of the applications especially in telemedicine includes the ability to scan through lots

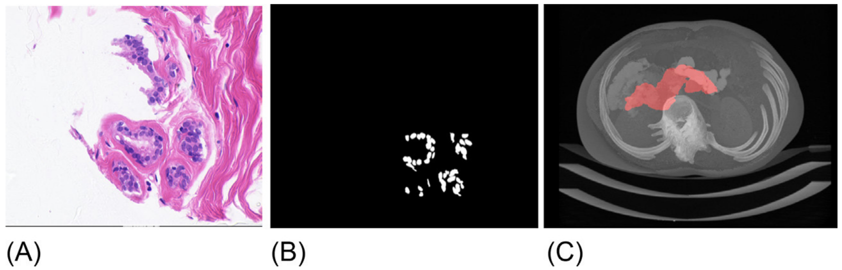

FIG. 4 (A) Breast cancer cell original (B) segmentation. (C) Pancreas segmentation from CT scans.

of X-rays, CT scans, and MR scans to provide a second opinion or reduce the workload. However, a key benefit of these systems, often overlooked, is that by training them on high-quality examples, we can now replicate best medical practices to all bringing a level of standardization and scale that is needed in healthcare. Though radiologists are especially at risk, it is unlikely that AI systems are going to replace doctors anytime soon. However, their potential in highlighting problems that assist the doctor to focus on the final interpretation is undeniable.

Developing drugs: Drug development is an expensive process. AI can be used at various stages of the drug development process such as identifying targets for intervention, discovering drug candidates, speeding up clinical trials, and finding biomarkers for diagnosing the disease. For instance, AI can help speed up trials by identifying suitable candidates by analyzing demographic and history data. AI can also detect early signs of a trial not going well so investigators can intervene sooner. For drug candidates, AI algorithms can analyze a molecule's structural fingerprints and descriptors to identify high-value prospect molecules.

Personalized care: How each of us reacts to a drug and treatment is different. Designing personalized treatment plans both at the care, as well as at the drug level is tedious and costly. AI can change how we prescribe drugs. Using data from electronic health records and the composition of a drug, AI system can predict which aspects might not react well with a patient and thus alter the treatment plan.

IoT?

IoT short for Internet of Things refers to interconnection of various day-to-day objects and devices such as a refrigerator, a watch, and an ultrasound scanner. to the internet enabling them to send and receive data. Let us consider just your future home, something which is current in many advanced countries, that is, the use of Alexa (Amazon©) and Google Home© to start music or the TV or search the net for answers. Since they can be activated remotely also, it has become possible to use these and other methods in what are smart homes to switch on the heater before reaching home. A smart refrigerator can check the available quantity of food and order the grocery directly. Similar connected devices can create data for healthcare purposes too with radical implications for ambulatory and outpatient care.

Applications of IoT in healthcare

The latest Apple watch has an EKG built in; this can be analyzed through AI. Body patches can live-stream vital signs. Weight can be accurately quantified and continuously monitored by sensors in your shoes.

Smart mattresses can relay information about how well you sleep. Wi-Fi routers can identify people by how they walk and even signal the hospital to send an ambulance in case they experience a fall.[497] More precise sensors can monitor breathing and heart rates with 99% accuracy. The sort of intelligent applications and devices that will be built using all these sensors is exciting but still vastly unexplored. Some examples are as follows:

Medication compliance: World-over, incorrect, or inconsistent intake of medicines is an issue. Even small improvements in compliance can dramatically save money and lives. Wi-Fi signal can help identify if the elderly is not making the required trips to the medical cabinet. Weight sensors in smart pill bottles or even sensors in the blister packaging can alert if doses of medication are being missed or an overdose is occurring.

Workflow optimization: IoT in healthcare means increased real-time visibility across the organization. Now, you have data about what the patient was doing, his vitals, and medication compliance before he visits the hospital and data about the patient flows through the hospital, for instance, when the tests were ordered, the images reviewed, and the ECG (report). AI can then be fed all these data, and healthcare providers can identify bottlenecks affecting patient wait times, reduce costs by avoiding unnecessary tests, and predict when would be the right time to discharge a patient.

Remote monitoring: The biggest application of IoT in healthcare is remote monitoring because of the tremendous cost benefits to health providers and the preventive nature of care to patients. By combining IoT and AI, we can also proactively intervene and save lives. Take congestive heart failure (CHF)—when a patient is discharged, a common problem is that CHF can resurface if swelling in the foot is not monitored properly. With IoT and AI, we can deploy sensors in socks or other wearable devices to monitor if the foot is swelling to alert the medical team to take action. Robots are already working and corresponding with specialists in stroke clinics and ICUs.[483] Fall detection in the elderly can be achieved by apps within the phone itself![498]

Challenges in AI and IoT

It is easy to get carried away and start imagining that these technologies can replace healthcare providers, but that, as of now, is a tall order, even for radiology, the first specialization possibly thought to be replaceable.[499] There are many challenges associated with these intelligent systems, listing here a few:

Bias: It is important for healthcare providers to evaluate the data that were used to train these systems and ensure that bias does not creep

in. An AI polyp detection system trained using diagnostic data from a US population will not be as effective in identifying the peculiarities associated with the South Asian phenotype. Similarly, the data being used to train an AI system need to account for variations in ethnicity and environmental factors.
Black-Box: One drawback of deep learning-based AI is that patterns may not be understandable or visible. Very often, one cannot explain why a particular diagnosis was recommended by the system. This is an active area of research; until then, it is important to ensure that a human layer is present to help explain odd conclusion.
Failure: AI systems, just like humans, can fail. There is much technology behind it. And eventually, the key to continued use is a persistent personalized linkage, that is, the local Wi-Fi, Bluetooth, etc. to a provide access to the World Wide Web. Processing of information involves generally a linked mobile device, which mostly is also the mode of transmission. A failure to link or even a temporary loss of the connectivity can cause problems. The smaller devices may run on a battery, while the large ones like a refrigerator have no problem of electricity, etc. but in any case, if power goes out, the device is literally powerless!

Often, it is not the AI system that fails but failure results from human operational errors like deployment issues, training problems, incorrect software version, and incompatible hardware. In several accidents recorded by self-driving cars being tested in the United States, the operator had stopped paying attention to the system alerts because he wasn't driving!

Voice or emulated speech is used to communicate to the responder, sometimes, like for falls in the elderly, a phone call to the emergency. Other times, pop-up is displayed on a screen at the place where the relevant healthcare provider would be able to take action. There is always an issue of false alarms that is well described for fall systems,[498] besides ensuring that the relevant person is there at all times to answer calls. Both would be less of a problem once the systems mature.

Accountability: Robotic surgery had been linked to 144 deaths in the United States at the time of this writing.[490] Who is accountable when a death happens? The company, the developer, or the operator. AI and IoT warrant significant changes to our legal systems, privacy laws, and also employment agreements, and most of these are yet to happen. *You can jail Alexa if she makes a mistake, but you can be rest assured that even in jail, she will merrily continue talking without regret.*

It is well understood that the potentials of AI and IoT outweigh the risks. The right way to think of AI in healthcare is to design the perfect human-computer symbiosis. For example, instead of building an AI that replaces the doctor, how about we let an AI system ask intelligent questions and use IoT to collect the patients' data in near real time, process and summarize them, and then give the specialist all the information they need to make the diagnosis. p Learning?

Virtual reality in health

Amadeu Campos de Nutes

Virtual reality (VR) is not a new concept, but is nevertheless considered revolutionary for the development of applications in the health arena. This is related to the new possibilities it offers for the interfacing system or user; the use of multisensory devices; navigation in three-dimensional spaces; immersion in the context of the application; sharing and interaction in real time; and extending the senses previously linked to simple vision, hearing, and three-dimensional manipulation for touch, pressure, and even smell through the use of devices such as head-mounted displays (HMDs), gloves, or the user's own body.

In many situations, VR is confused with augmented reality (AR). While in VR, the user navigates, observes, and immerses himself in a three-dimensional virtual world in real time, in AR, the real world is used to visualize and interact with virtual objects, giving the illusion that the real world and the virtual world are mixed. Unlike virtual reality in which users immerse themselves in a virtual environment, augmented reality does not take a user into a virtual environment. Instead, AR lets the user view virtual objects within real environment, whether by the use of tablets and smartphones or devices such as glasses.

The origins of VR can be traced in 1838 when Charles Wheatstone's research demonstrated that the brain processes the different two-dimensional images from each eye into a single object of three dimensions. In Table 1, we can visualize the evolution of virtual reality concept over time.

After the 1990s, there were several unsuccessful attempts to further evolve the concept of VR technology. During the same period the internet became popular, diverting everyone's attention, and VR was temporarily forgotten, understanding that it was not easily accessible. This period of lapse and forgetfulness of VR started in the 1990s and lasted till about 2010.

After 2010, there have been significant and rapid advances in the development of virtual reality applications due to the emergence of mobile technologies, especially the rise of smartphones, which were small and powerful, but armed with high-density displays. Inbuilt 3D capability and other graphics features like virtual light enabled a generation of reality devices. In addition, the video game industry continued to drive the development of consumer virtual reality without interruption. Another

TABLE 1 Evolution of virtual reality over time.

VR technology	Years
The stereoscope	1838
The view-master	1839
The lenticular stereoscope	1849
Link trainer-the first flight simulator	1929
Science fiction story predicted VR	1930s
Sensorama	1950s
The first VR head-mounted display	1960
Headsight—first motion tracking HMD	1961
The ultimate display	1965
Sword of Damocles	1968
Artificial reality	1969
GROPE—force-feedback system	1971
VIDEOPLACE—artificial reality	1975
VCASS—visually coupled airborne systems simulator	1982
VIVED—virtual visual environment display	1984
BOOM box	1989
UNC walkthrough project	1990s
Arcade games and machines	1991
CAVE	1992
The lawnmower man	1992
SEGA VR glasses	1993
Nintendo virtual boy	1995
Google glass, cardboard, oculus rift	21st century

advancement of smartphones that contributed to the use of VR was high-end sensors like camera depth detectors, spirit level, proximity sensor, and motion controllers. Many can simulate natural human interfaces and are already a part of the daily tasks of human computing.

Nowadays, VR has been attracting much interest. Being a new user interface paradigm, it offers great benefits in many areas of application such as entertainment and gaming, flight simulators, data visualization systems or architecture,[500,501] modeling systems,[502] planning and design, teleoperation environments,[503] and collaborative systems.[504]

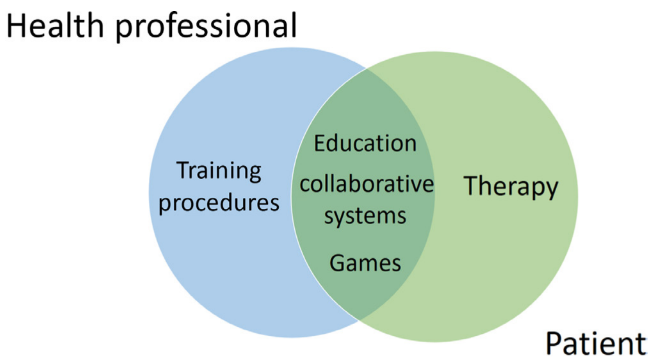

FIG. 5 Categorization of virtual reality application in health.

In health, virtual reality applications can be categorized according to their purposes such as, for example, qualification of the health professional in a given scenario, training of procedures, education, simulation, rehabilitation, treatment of phobias, and diagnosis of diseases. This categorization may still consider the target audience, as shown in Fig. 5.

Training of health professionals and teaching of procedures to medical students are among the most commonly used VR applications for health. These applications aim to prepare students, technically and psychologically, to develop real tasks, to assist the educational process in different age groups, to offer professionals the means to train new techniques simulating different generic situations, and to facilitate the teaching of how to behave while attending to patients. As an example, Ragazzoni et al.[505] used virtual reality to perform training and virtual simulation for infection control and management of Ebola virus treatment. In this context, virtual reality provided a realistic and effective educational structure and opportunity to provide virtual exposure to the public health operational skills that are essential for infection control and management of Ebola virus treatment. This training is designed to increase staff safety and create a safe and realistic environment where health professionals can acquire basic and advanced skills.

In the educational context, Izard et al.[506] developed a software to illustrate the potential of virtual reality in the learning the human anatomy. Virtual reality software uses stereoscopic glasses to allow users to have the feeling of being in a virtual environment, clearly showing in 3D the different bones and shapes that make up the skull. All content is accompanied by audio explanations. Another example that used VR as a support to the teaching-learning process was developed by Silva et al.[507] who researched the students' satisfaction with the use of an VR application based on serious games for teaching the digestive system. The application, in addition to using the VR goggles also used a control for better interaction and learning with the elements of the digestive system. The study showed

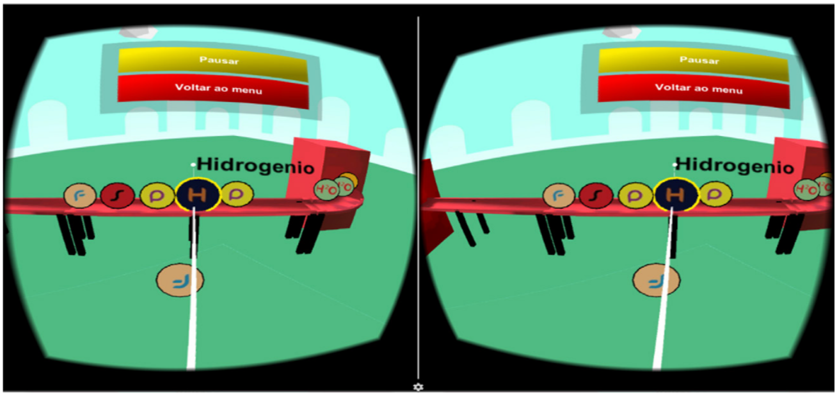

FIG. 6 Virtual reality application in the form of VR goggles.

there was evidence that the preference of all users in favor of using the VR platform as a teaching support tool relates it with its simplicity and the possibility of immersing within a virtual environment of the human body and viewing in 3D its elements (Fig. 6).

There is a growing interest in virtual reality-based programs designed to positively impact overall health and well-being. Of late, virtual reality has been used to facilitate rehabilitation through the exercise that aims to promote health. Campelo et al.[508] presented a model of virtual rehabilitation (VRehab) applied to the elderly, considering the promotion of health, rehabilitation, and injury prevention. In addition, Shin[509] in his studies added the strategy of digital games along with virtual reality for rehab exercises. These types of games can be classified into motion-based, serious game and virtual reality game.

In the field of medical procedures, educators began to introduce virtual reality in about 1997 as a tool with high potential of use for training of medical procedures and for treatment of several physical and cognitive deficiencies. They used VR to train medical students in practical experimentation and to improve their repeat practices. VR environments provide the opportunity to repeat a procedure at any time of the cycle and minimize the risk of being in contact with the patient and recreate instances of surgical tool related accidents. They had shown that training in virtual environments can improve the portability of information, reducing training time, cost, and errors.[510,511]

Virtual reality teaches surgical procedures to medical students better than the standard practice of video demonstration.[503] Gonçalves et al.[512] found advantages through use of VR allowing simulation of medical procedures. Their research focused on three-dimensional (3D) modeling of breast structures for the detection and diagnosis of breast lumps.

The training of psychomotor skills and surgical procedures of medical students and residents in distance surgery before entering the operating room is another area that has been using VR technology. The training is carried out through a virtual reality environment with the real-time transmission of high-resolution (8K) 360-degree videos from a surgical room environment for the teaching of resident physicians and undergraduate students in surgical procedures. Video recordings of surgical procedures are transmitted in real time over the internet and students can watch using VR goggles or smartphones.

Pulijala et al.[513] have developed Oculus Surgery, a virtual and immersive environment of an operating room for surgeons interning in maxillofacial surgery. The technology uses VR goggles, hand-motion tracking devices, high-resolution stereoscopic 3D videos, and 360-degree videos. This application allows a trainee to participate in a surgical procedure and interact with the patient's anatomy. Oculus Surgery is useful for surgical trainees as a visualization aid and for senior surgeons as a practice-based learning tool. Similar applications exist for surgeries where video is constant, for example, laparoscopic and endoscopic procedures.

In relation to the treatment of phobias, Monge et al.[514] proposed the VRPhobia, which is an interactive virtual reality system that improves the visual and auditory parts of the therapy, placing the patient in a virtual world that provides stimuli to face their phobias such as imagining scenes or situations they are afraid to face in the real world. In this virtual environment, they can learn the proper techniques to learn how to respond to anxiety triggers. The system is based on the techniques used by the therapists and the training that the patient undergoes. It works as a tool that improves the therapy process.

Blockchain

Fernando Sales

Transactions are the basis of the trust-based systems where people interact with each other, for example, healthcare and finances; however, the exact process of creating trust continues to evolve.[515] In general, financial operations must be registered for accounting purposes,[516] and formal recognition of a valid transaction between two parties, usually, needs attestation by a third party that in turn provides trust to the whole financial system.[517]

In health and medical care, data about health moves between patients and doctors/nurses/caregivers. This exchange is based on trust. Transactions need to be recorded and organized in a way so that they are not tampered with. Nodes in such transactions are patients, doctors/nurses/healthcare providers, and the points of care.

For example, suppose that a pharmacy company decides to publicize the prescription drug receipts for an educational campaign about antibiotic usage, some sensitive information like the personal identification data needs to be encrypted, but every other nonsensitive data can be allowed public access. This is a typical case for blockchain.

Every transaction is recorded as a block that is added to the blockchain, and any person interested in accessing the information may read it, without the need of previous authorization of the pharmacy company. Using blockchain, data from operations are safely stored, and some level of secrecy is kept for sensitive data. There are several additional examples of blockchain applications that may be found in this chapter references.

Blockchain is a public decentralized ledger, where the valid peer-to-peer transactions are recorded in a distributed chain of blocks, with constant updation as long as some new approved transactions take place.[518,519] As soon as a block is appended to the blockchain, the update is transmitted to the entire distributed structure, providing redundancy, transparency, and security.

The components of blockchain technology are

- nodes that contain the database of ledgers and current state of transactions
- ledgers themselves that include transactions
- contracts (smart contracts)—the consensus that governs the regulation of the transaction network; this eliminates the need for "trust" that is traditionally used in transactions such as banking and healthcare delivery and information exchange
- consensus networks that enable the contracts
- wallets—these manage the identity of the users in the network

Bitcoin (BTC) and Ethereum are examples of public blockchain. As of 2008, what could be called a revolution was initiated with the proposal of Bitcoin (BTC)[518] and its actual release the following year. BTC is an innovative electronic cash system to provide peer-to-peer trusted transactions without the need of a third-party validation.[517]

In the financial context the trust provider role was largely fulfilled by banks.[517] In the beginning of the third millennium, however, the internet and e-commerce brought about a new set of demands for digital operations with inbuilt technical challenges, largely associated with information security issues and a possibility of fraudulent and nontraceable transactions.[519] However, for long, this digital system kept on with the old assumption, and trust was provided by a restricted set of institutions.

The independence from a central authority to trust the transactions was a paradigm shift and the major contribution of BTC. It opened new perspectives to a wide variety of electronic transactions, not just limited to the financial system. However, one of the major concerns of BTC's creator was to protect the identity of the peers. To achieve this, sensitive data about the parties involved is encrypted and its hashkey—a sort of a signature code, used to attest the authenticity of the parties—is made public.

Even if a local block is tampered by any malignant system, it will remain different to the other branches of the redundant chain, reducing significantly the odds of a fraudulent transaction and providing certain level of security to the blockchain.

Based on these features, blockchain has been called "the trust protocol" and may be the technology responsible by the new internet generation: "the internet of value."[517] With blockchain technology, a new era of decentralized applications has risen, allowing peer-to-peer interactions, which are useful in the IoT context.[520] Smart contracts can be firmed between two different applications, providing new horizons to the machine interactions. For example, the logistics sector will be dramatically impacted, especially when automated delivery systems will be launched.[521]

In healthcare, several applications to blockchain have been developed, and new products and services are being created.[522–524] The important aspect is allowing the possibility of sharing medical data anonymously, which can allow new multicentric trials and unfettered access to clinical information, something very useful for clinical research.[525] There are fresh business opportunities in personal health data and their commercial exploration. Technology companies have joined the personal healthcare market, offering products and services for prevention and monitoring vital signals such as heart rate, pulse oximetry, blood pressure, and 1-lead electrocardiograms.[526–530] Data is stored in private clouds and maintained by companies who use them to build other products using machine learning techniques.[526,530–532] Even though maintained by the providers, such data that belonged to the patients could not be monetized previously. Now, there are possible revenue models that allow grant of access even while maintaining the required anonymity.[533]

Another example of blockchain-based healthcare applications is an online personal health record (PHR)[534] in which patients' data can be stored and made available, preserving privacy and allowing the data owners to provide access to their data. This example, also known as *omniPHR,* has interesting features because it uses *openEHR*[535] standard, which allows interoperability by means of other standards as *HL7*[536] and *SNOMED-CT*.[537] A performance assessment was performed, and *omniPHR* had an average response time below 500 ms, which can be used in real applications. Besides the previously mentioned, there are several other examples.[538–541]

Blockchain may be pioneering a new revolution, similar to the one enabled by the internet at the turn of the millennium, as described in the book by Chris Anderson *The Long Tail*,[533] which describes the impact on oligopolies by the digital revolution. Internet allowed new companies to enter consolidated markets by offering online services on demand, direct to the consumers. Amazon is a prime example—it started through online book publication but is now among the largest companies worldwide.

Despite its potential, blockchain does have some issues with relevant questions about the future of this technology: scalability and security[542,543] Bitcoin's transactions have been raised exponentially in the last years, with concomitant increase in the amount of data mining operations, electrical power consumption, and computational cost. In terms of security, blockchain is considered a secure application once it uses AES-256—Advanced Encryption Standard using 256 bits, an advanced algorithm for data encryption and decryption, the latest and best security standard, but how long it will remain is a moot question. Despite such risks, blockchain is already being used in different scenarios and in several applications, demonstrating a potential to change the way that data can be securely saved in the internet. The next section of this chapter, discusses big data a natural follower of this theme.

Big data

In line with Moore's law and faster communication, there has been an exponential growth in the amount of digital content generated and released online, leading us to the "information era." The term "big data," though widely used, lacks a formal definition. However, common sense dictates that "big data" refers to large amounts of data, around hundreds of terabytes (~100 TB), and unstructured formats and generally results from a continuous data flow.[544]

The term "big data" has become viral in the last 5 years. The concept was introduced in 2001 in a technical report written by Doug Laney of Meta Group that described the *three dimensions of data management*: volume, velocity, and variety.[545] Briefly, *volume* is related to increasing amount of data generated and collected, which needs to be processed and stored; *velocity* describes the speed of data transmission and performance of applications, which will necessarily be affected by rising amounts of data and how speed is retained. The third dimension, *variety*, is related to the diversity of data sources and the related need for standards to allow sharing and interoperability.

Additional dimensions have been added of late to this paradigm: *veracity* and *value.*[544] Both are contemporary themes, as it is important to address the authenticity of the information and, also, its value.

Healthcare is one of the sectors that produces large amounts of data from a variety of sources and needs to be quickly accessed for decision-making.

In clinical care, these sources make up the electronic health record, such as laboratory data, medical prescriptions, medical imaging data, genetic data, and prescription notes, along with the administrative data. Some potential applications of big data in health are related to predictive medicine, patient monitoring, clinical and administrative performance improvement, and production of genetic knowledge, among others. Big data's capacity in the health sector is defined as "The ability to acquire, store, process, and analyze large amounts of health data in a variety of ways and provide meaningful information to users, allowing them to discover business values and insights in a timely manner."[546]

The last few years have witnessed an increase in the variety and quantity of medical devices connected to the internet, some of which are in the form of "wearables." As of 2019, there are several biomedical signals and biomarkers being recorded and transmitted to the cloud for further analysis and to support a healthier living. This ongoing revolution includes individuals using devices to measure and quantify their daily health indexes, like the total number of steps traveled and the total duration of REM sleep every night.

Personal wearables have been feeding private large databases with personal health information. Worldwide, millions of daily users provide data that can allow large populations studies.[547,548] Inspired on this trend of personal healthcare monitoring, the *National Institutes of Health* (*NIH*) has launched the "All of Us Research Program," which aims to gather data from 1 million or more people in the United States for research purposes.[549]

Programs like this have the power to generate big data applications. They also permit analysis of different random subgroups with low bias, which can be helpful to establish causal inference,[550] which is defined as a statistical approach focused on studying the "cause and effect" relationships between variables. Using big data is more specific and more impactful than correlation through regression analysis,[551] especially when trying to establish new management strategies or new treatments.[552]

For example, the 100 million Brazilian cohort funded by several institutes gathered and integrated different data sets of personalized information to assess the impact of several social protection programs on health, education, and work, among others.[553] Cohort studies are valuable because inferring causality through confounding variables is challenging. Cohort studies are not easy to design if working on a prospective basis,[9,554] but do become possible if digital health data is utilized as exemplified by the NIH's "All of Us Research Program."[549]

Several approaches and new technologies have been developed to manage large data volumes, fulfill performance requirements, and integrate different data sets into large data lakes, to permit the data analysis process. The most used tools are open source,[555] for example, Hadoop[556] and Spark.[557] These are available in Python, one of the most popular programming languages for data science applications worldwide.

The conjunction of IoT, wearable medical devices, high-speed connectivity, and blockchain have been generating big data applications, where there has been a rising trend to use a business analytics approach, to learn from the data, from clinical trials to the local enterprise, a relatively new concept though predicted some decades ago by authors like Peter Senge,[558] who described the term "learning organizations," responsible for transforming several industries including the healthcare sector.