Overview of Trending Medical Technologies

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ABSTRACT

Healthy population is regarded as the most valuable asset of any country. Unfortunately, the health challenges that hinder mankind's wellbeing are enormously increasing. Examples include but are not limited to: the diversity of emerging diseases afflicting the global population, the projected demographic growth of elderly people who need consistent monitoring, the deficiency in medical staff, the lower density of physicians, and the challenging geographical location of the population from healthcare providers. The mitigation of such health challenges calls for novel technologies to improve patient outcomes. In this article, seven emerging technologies, namely: Wearable Devices and Internet of Things, Artificial Intelligence, Blockchain Technology or Distributed Ledger Technology, Robotics Technology, Telehealth and Telemedicine, Big Data Technology and Nanomedicine have been highlighted. For each discussed technology, its historical background, development drivers, market status and trends, significance to healthcare, key player companies, and associated challenges have been presented. The information contained in this paper was collected from different journal articles, websites, reports, conference proceedings, and books. It was observed that though the technologies discussed in this article show growth at different rates, healthcare technology development and implementation are very promising in revolutionizing the health sector and improving the health of the population. Therefore, healthcare providers and countries are recommended to put in place Healthcare Technology Assessment Programs to help them collect data regarding the technology efficacy, relevance, safety, outcomes, and alternative technologies towards better planning for healthcare services improvement.

Keywords – *Wearable devices, Internet of Things, Blockchain, Telehealth and Telemedicine, Artificial Intelligence, Big Data, Nanomedicine, Market, Drivers, Challenges and Companies.*

INTRODUCTION

The triumph of modern medicine is axed to the emerging technological innovations, and there is no doubt that the medical expenditures and life expectancy are variables driven by technological progress.[1-2] Medical technology uses scientific knowledge to improve healthcare by new and improved equipment to make work easier, pleasant, quick, and productive.[3] The management and treatment of diseases have become largely dependent on innovation and discoveries in newer drugs, surgical techniques, diagnostic and therapeutic equipment.[3] Medical doctors themselves are becoming more reliant on technology to diagnose and carry out treatments.[4] The scope of medical technology is vast; it covers consumables (bandage, syringes, hearing aids, wheelchairs, etc.), implants (hips

and knees, stents, pacemakers, etc.), medical equipment (imaging machinery, dialysis equipment, etc.), and in-vitro diagnosis.[5] Technological innovations are appreciated by the general population because they enable a 4P-model for medicine (predictive, preventive, personalized, and participatory).[6]

The factors that reinforce the market for medical technology include advances in science and engineering, patent protection, increasing prevalence of chronic diseases, aging population, emerging pathogens, financial incentives of technology companies, mass media reports, public demand driven by direct-to-consumer advertising, consumer awareness and advocacy, rising prices of physician and hospital services, off-label use of drugs and devices, malpractice avoidance, strong and growing economies.[7-8] The maintainability of high quality of life in the aging population is probably the most significant underlying global which requires requiring technological mindset.[9] For example, Japan has the longest life expectancy, and its aging population ratio is still increasing.

This has called for rising expenditures, giving concerns about the future inflation of health costs.[10] In 2050, 16% (1.5 billion) of the world's population will be above 65 years old.[11] In China, 2.4 young people will have to support 7.9 old people in 2050.[11] The physical nature, purpose, and stage of diffusion constitute the three ways to describe a healthcare technology.[7] According to the stage of diffusion, medical technologies classification is presented in Table 1.

TABLE 1. Classification of Medical Technologies According to the Stage of Diffusion[7]

Medical Technology Class	Explanation
Future	in a conceptual stage, anticipated, or in the earliest stages of development
Experimental	undergoing bench or laboratory testing using animals or other models
Investigational	undergoing initial clinical (i.e., in humans) evaluation for a particular condition or indication
Established	considered by clinicians to be a standard approach to a particular condition or indication and diffused into general use
Obsolete/ outmoded/ abandoned	Superseded by other technologies or demonstrated to be ineffective or harmful

Today the actual figures for medical technologies are not available, but it is estimated that 500,000 different types of medical devices are in service.[12] From 1960 to 2007, health care expenditure in OECD countries increased, on average, from 3.8–9.0% of GDP.[1]

In 2020 it was forecast that the global market for medical technology would achieve a volume of 490 billion euros.[11] In 2025, global turnover for medical devices is estimated at approx. 615 billion dollars.[11]

The main categories of healthcare technology include but are not limited to: drugs, biologics, devices/equipment and supplies, medical and surgical procedures, public health program, support systems, organization, and managerial systems. However, not all technologies fall neatly into the category, and certain hybrid technologies combine drugs and devices.[7]

In the past decade, the medical technology revenues have increased by 44.7% (USD 352.[9] billion to USD 510.[9] billion for 2011 and 2021, respectively), and the forecast is to reach USD 594.5 billion in 2024.[13] In 2022, the strongest medical technologies segments will be in cardiology, imaging diagnostics, orthopedics, and surgery. These technologies will account for 50% of the market.[11] Although there are giant companies in medical technology, 95% of all medical technologies businesses are small and medium-sized companies (SME), with the majority having fewer than 50 employees.[11] As of 2020, Medtronic Inc. was the leading medical technology company with a revenue of 30.[12] billion USD.

It was seconded by Johnson&Johnson with total revenue of 23 billion USD. In a survey conducted about medical technology in Belgium,[5] 106 companies participated, and the results are that 67.9% were active in medical devices-consumables, 15.1 % in In-vitro diagnosis, 12.7% in pharmaceutical products, 6.6% in para-pharmaceutical products, 43.4% in medical software, 40.6 % in implants and 45.3% in medical equipment and systems. Medical technologies are classified into preventive, screening, diagnosis, rehabilitation, palliation, and treatment types.[7]

The technological acceptance and use expansion vary from society cultures. The Technology Acceptance Model developed by Davis, Theory of Planned Behavior, and Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) developed by Venkatesh showed that perceived

usefulness, perceived ease of use, price value, and habit are the key factors that determine the application and market expansion of a particular technology in a certain region.[14,15] In addition to those factors, commercial-grade, durability, reliability, sustainability, technical support, disinfection, alarm management, network, and device security also advocate adopting a particular technology.[16,17]

LITERATURE REVIEW

It is not easy to cover all details of the medical technologies available in a single paper due to their diversity. In this paper, the following trending technologies are looked at: Health Wearables and Internet of Things, Artificial Intelligence (AI), Blockchain Technology (BCT) or Distributed Ledger Technology (DLT), Robotics Technology, Nanomedical Technology, Telemedicine and Telehealth, Big Data

Health Wearables and Internet of Things

Environmental, psychological, behavioral, and physiological domains that adversely impact the quality of life are recognized by the World Health Organization.[19] Wearables as medical technologies are becoming part of personal analytics, measuring physical status, recording physiological parameters, or informing schedules for medication.[20]

The journey of wearables started with the invention of spectacles around the 13th century by English friar Roger Bacon.[21] Growth in wearables was slow until the 20th century, when in 1907, the first portable camera was put on the market. Since then, the pace of developing new devices never ceased to increase until 2014, when android wearables were commercialized. The whole evolution of wearable technology is picturesquely presented in the chronological sequence in Figure 1.

From a monetary perspective, the market of wearable devices is anticipated to grow exponentially at a rate of 20% and is expected to reach 150 billion EUR by 2028, as presented in Figure 2.
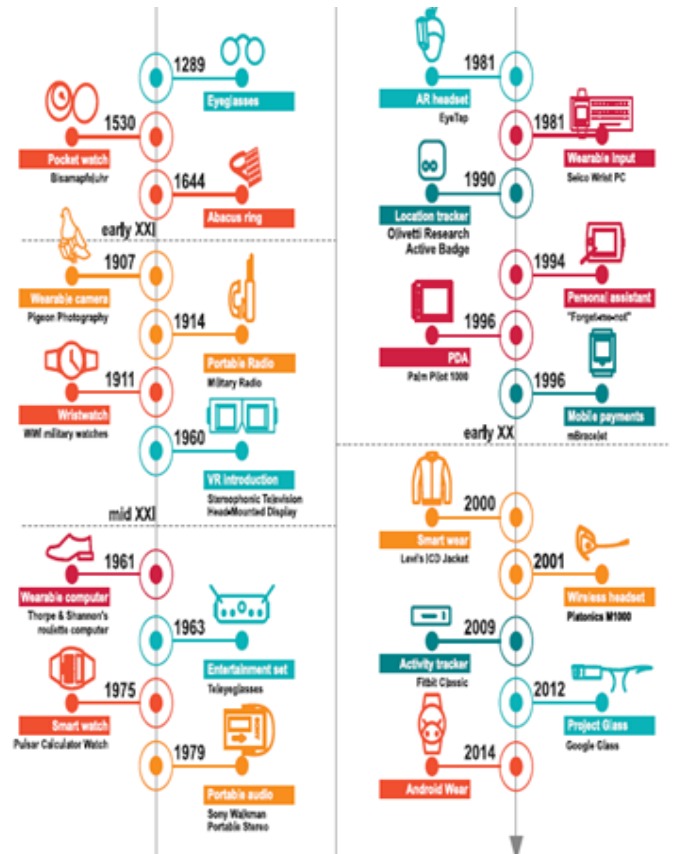

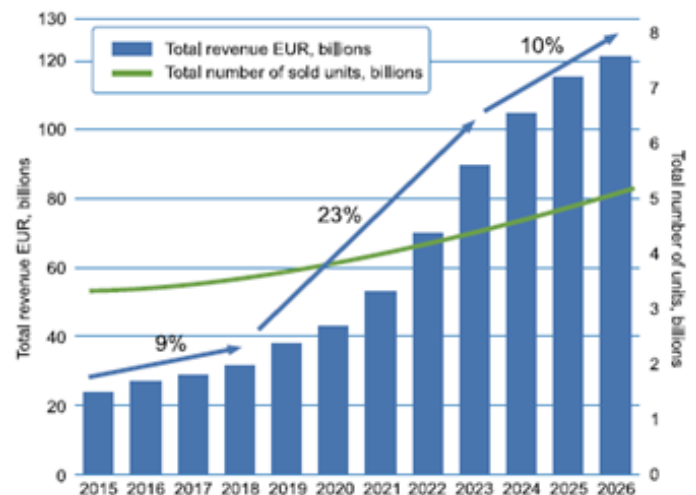**FIGURE 1.** Evolutional milestones in wearable devices.[21]

FIGURE 2. Wearable market growth forecast.[21]

In the third quarter of 2021, the Chinese market shipped 35.28 million units across the globe,[22] and the market was dominated by Huawei.[23] From a technological point of view, wearables are self-contained devices with embedded sensors worn by the user to detect, diagnose, monitor, and communicate the health and performance data of the user.[24] Wearable technologies include smartwatches, wristbands, hearing aids, electronic/optical tattoos, head-mounted displays, subcutaneous sensors, Smart belts, electronic footwear (Smart shoes and socks), and Smart textiles (Smart pants, Smart shirts).[20,25] Generally, wearables devices are composed of five components: sensors, connectivity, battery, interface, materials/algorithm.[25] From the design and manufacturing consideration, wearable devices contains microprocessors, interface including data communication, different types of sensors: inertial measurement units (gyroscopes, accelerometers, barometers, and magnetometers), optical sensors (complementary metal-oxide-semiconductor [CMOS]) sensors, spectrophotometers, cameras, temperature sensors, chemical probes, electrodes, microphones, shock detectors, strain gauges.[20]

These days, when the world is dealing with COVID-19, vital-sign wearable solutions were implemented in different countries. Wearables can provide a key early-warning system about the likelihood of COVID-19 infection and its surveillance.[26] For example, in Singapore, ViSi mobile developed by Sotera was used as a wearable device on patients in mild illness to monitor heart bit rate, respiratory rate, body temperature, and oxygen saturation.[16]

Wearable devices find different application in biomedical and clinical services, as shown in Figure 3.
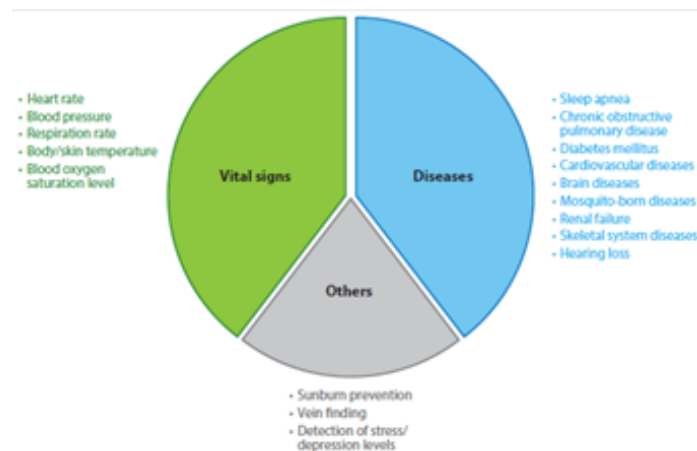

FIGURE 3. Some biomedical applications of medical wearables.[27]

Apart from measuring vital signs, aggregate data taken from wearables can also contribute to the research by detecting general patterns and trends within a population, contributing to improved public health responses.[26] Wearables are positioned to different body parts depending on the parameter to be measured, as shown in Figure 4.
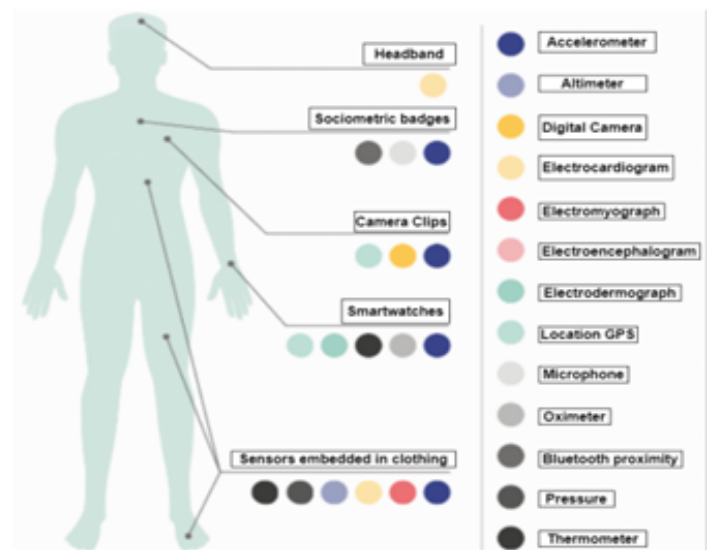

FIGURE 4. Wearables based on on-body location.[26]

Wearable devices come into 4 main classes[25]:

- **Lifestyle and fitness devices.** This includes fitness trackers, sport and activity trackers (e.g., Moov Now, Misfit Shine, Fitbit charge2).

- **Diagnostics and monitoring devices.** These non-invasive devices provide valuable health information (e.g., DexcomG4, Quardio Core).

- **Therapeutic devices.** These devices monitor disease states, track activity, store data, and deliver feedback therapy (e.g., Quell, Minimed530GInsulin Pump).

Injury prevention and rehabilitation devices. This includes body motion monitoring devices, wearable sensing garments, fall detection devices (e.g., Philips lifeline, sprouting baby monitor).

The International Electro-technical Committee Standardization Management Board Strategic Group10 distinguishes wearable technologies into near-body electronics, on-body electronics, in-body electronics, and electronic textiles.[17,21] Wrist-worn and handheld wearables are the most widely adopted and market-filled niche covering

Smart rings, wrist bands, smartwatches, and gesture control devices.[21]

Unlike conventional testing in a clinical setting, which may occur a few (or less) times a year, wearables offer continuous access to real-time physiological data.[28] In their use, wearable devices are applications of the Internet of things, a concept used by devices for sending and receiving data via the Internet.[18] Embedded intelligence connectivity offers a unique opportunity for condition monitoring, localization, identification, personal contextual notifications, information display, and virtual assistance.[21]

The wearables data processing cycle follows 6 stages, as presented in Figure 5.

The wearable market is growing faster in patients with specific conditions like epilepsy, chronic obstructive pulmonary disease, asthma, heart arrhythmia, chronic pain, and breast cancer.[17]

Today, many wearable devices are commercially available, such as rings, headsets, sleep masks, wearable patches, arm straps, finger clips, chest straps, fitness bracelets, fitness bands, and flex garments. Specific products include Google Glasses, GOW Pack, LUMOback, Metria Wearable Sensor Technology, nECG Platform, Peeko Monitor, PER-Smobile, NuMetrex Heart Sensing Racer Tank, Re-Timer, SleepShirt, T. Jacket, 360 Kids Guardian, and Vega.[15,24,29]
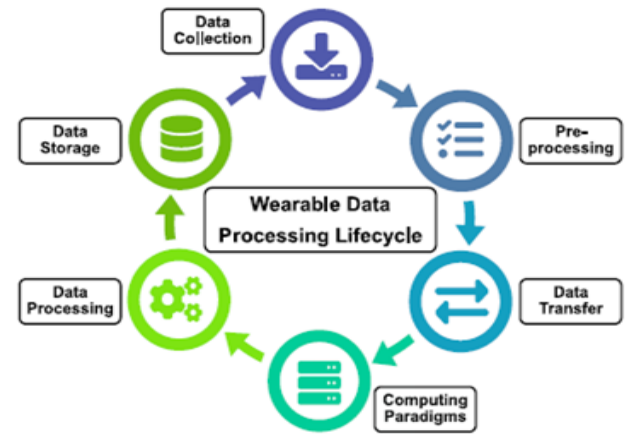

**FIGURE 5.** Wearables data processing cycle.[21]

Significant growth in purchased wearable devices has been recorded in North America, Western Europe, and the Asia Pacific region, while in the rest of the world, the market growth is lower. Reports about the future of wearable technologies predict that the market volume will be 27.8 billion dollars in 2022 and 93.[19] billion dollars in 2027.[18]

Some of the challenges of wearable devices include the feeling of constant surveillance, inefficient data analytics, lack of appropriate data labeling, insufficient computing capabilities, inefficient switching among resources in hybrid networks, lack of modern energy harvesting

TABLE 2. Wearable Wireless Technologies, Operating Frequency, and Range.[21]

	Communication Technology	Frequency Range	Range
Short-range	RFID	125–134 kHz, 13.56 MHz, 860–960 MHz	Up to 100 m
	NFC BLE (IEEE 802.15.1)	13.56 MHz 2.4–2.48 GHz	<0.2 m Up to 100 m
	Zigbee Zigbee (IEEE 802.15.4)	868–868.6 MHz, 902–928 MHz, 2.4–2.49 GHz	Up to 100 m
	Wi-Fi (IEEE 802.11a/b/g/n)	2.4–2.48 GHz, 4.9–5.8 GHz	20-250 m
	Wi-Fi 5 (IEEE 802.11ac)	4.9–5.8 GHz	Up to 70 m
	Wi-Fi 6 (IEEE 802.11ax)	1–6 GHz	Up to 120 m
	WiGig (IEEE 802.11ad/ay)	57–70 GHz	10–100 m
	VLC (IEEE 802.15.7)	400–800 THz	Up to 100 m
	VLC (IEEE 802.15.7)	LTE frequency bands	Up to 15 km
Long-range	LTE-M	LTE frequency bands	Up to 10 km
	LoRa	867–869 MHz	Up to 50 km
	Sigfox	868–878.6 MHz	Up to 50 km

opportunities, low data resolution.[21] The major market players in wearable medical technologies are: Apple, Fitbit, Jawbone, Misfit, Mykronoz, Samsung, Garmin Ltd, Xiaomi Technology Co. Ltd, Qualcomm Technologies, Inc; Adidas Group, Sony Corporation, Lifesense Group.[18] The details on many body-worn devices are presented in Figure 6.
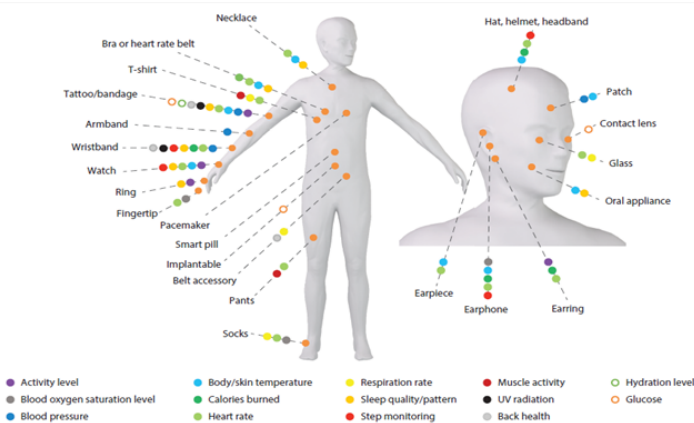
FIGURE 6. Wearable devices worn on various body parts and the parameters they can monitor.[27]

Artificial Intelligence (AI)

AI is rapidly evolving in clinical practice in dealing with a significant amount of data provided by Smart wearables, Smartphones, and other monitoring systems in medical services.[6] The concept of AI was first conceived in 1950 by Alan Turing in his book entitled Computers and Intelligence in what was called Turing test when he was trying to determine whether computers were capable of human intelligence. In 1956, John McCarthy described "Artificial Intelligence" as the science and engineering of making intelligent machines.[30] The systematic evolution of AI is presented in Figure 8. Today, AI is defined as using computers and technology to simulate intelligent behavior and critical thinking comparable to a human being or the science and engineering of making intelligent machines.[31-34]

The evolution of AI is presented in Figure 3. AI is not one type of machine or robot but a series of approaches, methods, and technologies that display intelligent behavior by analyzing their environments and taking actions—with some degree of autonomy—to achieve specific targets that can improve health services.[35,36] Studies about AI have

exponentially increased from 826 in 2012 to 12563 in 2019.[37] By 2019, there were 279,145 AI patent applications in the US, with the global market expected to reach 190.61 billion dollars in 2025. AI can add about $15.7 trillion to the world economy by 2030,[38] with China leading the global market in 2030 with a share of 26.1%.[39]

These assertions are justified by the research article published by Chinese universities from 2015 to 2019, as seen in Figure 7.
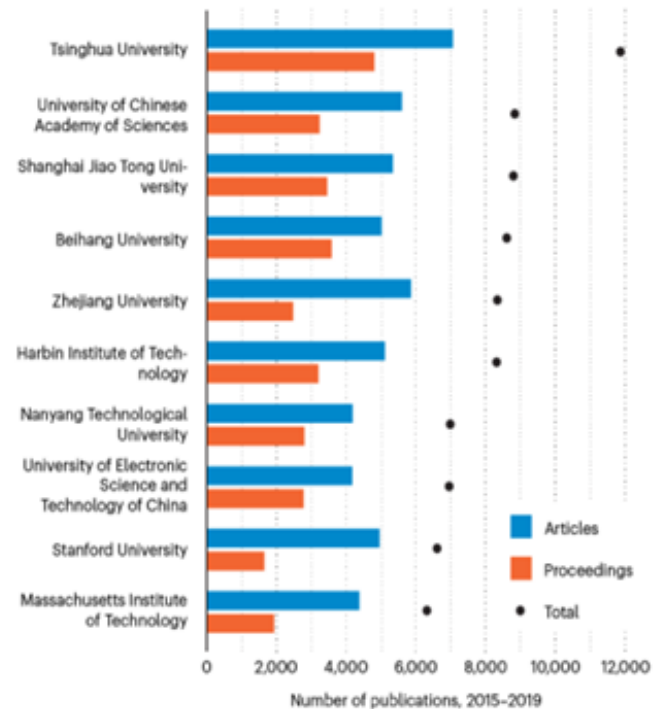
FIGURE 7. Top 10 institutions with the most AI-related publications (2015-2019).[40]

With AI, patients will receive more rapid, accurate diagnoses and reduced adverse events. The top applications of AI include robot-assisted surgery, virtual nursing assistant, administrative workflow assistance, fraud detection, dosage error reduction, clinical trial participant identification, preliminary diagnosis, automated image diagnosis, cybersecurity, health research, and drug discovery and development.[41] AI also finds application in diagnosis and case identification and prognosis and prediction.

The AI umbrella encompasses the following subfields[30]:

- **Machine learning (ML):** Machine learning involves training an algorithm to perform tasks by learning from

patterns in data rather than performing an explicitly programmed job.[42] Machine learning algorithms can automatically learn and improve from experience without explicitly programming. The most common algorithms of ML are: **supervised learning** (used when we can precisely define the task we want the algorithm to learn based on data that we already have), **unsupervised learning** (It is like learning without a teacher. We have a group of patients with different sets of data, but we do not know their individual diagnoses. We build a model, then try to cluster patients based on similar attributes such as the symptoms they presented with, their lab markers or age and gender), **Reinforcement Learning** (this allows the algorithm to learn how to complete the tasks with a sequence of decisions by itself without being told how to do it).[35,37]

- **Deep learning (DL):** It is a subset of ML with similar functions but with different capabilities.[37] This method of AI allows a machine to be fed with large quantities of raw data and to discover the representations necessary for detection or classification.[43] DL uses chips called graphics processing units to rapidly perform required calculations, a single card of which can potentially process hundreds of millions of images a day.[42] DL mammography is used for breast cancer detection, in computed tomography (CT) for column cancer diagnosis, in chest radiographs, for the detection of pulmonary nodules.[41]

- **Natural language processing:** This branch of AI is concerned with the use of computational methods in understanding and interpreting human language.[35,42] **Artificial Neural Networks (ANN) or Simulated Neural Networks (SNN):** ANN are considered the heart of DL. ANN is technology based on a human neural network.[44] Examples of ANN include handwriting recognition, speech-to-text transcription, weather prediction, and facial recognition.[45] An SNN contains a node layer, one or more hidden layers, and an output layer. Each node, or artificial neuron, connects to another and has an associated weight and threshold. If the output of any individual node is above the specified threshold value, that node is activated, sending data to the next layer of the network.[46] ANN are used in economics, ecology, environment,

biology. In medicine, the most widely used family is the multilayer perceptron (PMC) in therapeutic decisions to process data for anthropology.[47]

- **Computer Vision (CV):** CV allows the building of artificial systems capable of retrieving any information from an image previously obtained. CV involves different stages, namely: image acquisition (image capture with a sensor and transformation of visual information into digital information), pre-processing (preparing the image for the next level handling), feature extraction (detection of some objects to be analyzed), segmentation (separation of images into cohesive regions), noise reduction and high-level processing.[48] Today, there are many practical applications where AI was successfully useful.

**TABLE 3.** Examples of Success of Artificial Intelligence.[37]

Company	Application
Babylon Health	Software application for online consultation where the system gives medication based on the symptoms entered in the system
Sensely (developed Molly app)	A virtual nurse that was designed to have a smiling face coupled with a pleasant voice to assist patients with monitoring their health
Deep Genomics (developed Oncecompass Medecine app)	To match genetic mutations found in patients' tumor samples with ongoing clinical trials worldwide
IBM Watson	Software that provides evidence-based treatment options for oncologists
Atomwise	Uses supercomputers to root out treatments from a database of molecular structures

The key challenges of AI are their computing power, trust deficit, data privacy and security, data scarcity,38 ethical regulations, high resource and research cost, shortage of transparency, poor governance and accountability, notability of data annotation.[49]

Globally, the AI companies are NVIDIA Corporation, Amazon.com, Inc., Meta Platforms, Inc., DeepMind, OpenAI, Affectiva, DataRobot, Ubiquity6 CloudMinds.[50,51] To ensure appropriate utilization of AI, companies need to embrace techniques that help them achieve fairness, security, and explainability.[49]

TABLE 4. Applications of Artificial Intelligence in Diagnosis and Prediction.[43]

Diagnosis and case identification			Prognosis and prediction
Function	**Clinical area**	**Applications**	
Waveform analysis	Obstetrics	Intrapartum monitoring	Cardiovascular risk prediction, Prediction of breast cancer survival. Prediction of outcomes in colorectal cancer, Predicting of survival in non-small cell lung cancer. Prediction of hospitalization due to heart disease. Prediction of sepsis in the intensive care unit, emergency department, and hospital floor Prediction of treatment outcome in social anxiety. Prediction of psychiatric readmission from discharge summaries
	Neurology	Remote monitoring of gait	
Image processing	Pathology	Detection of lymph node metastases in breast cancer	
	Dermatology	Identification of benign and malignant tumors, identification of fungal infection, classification of skin cancer	
	Ophthalmology	Identification of diabetic retinopathy, grading of macular degeneration	
	Cardiology	Diagnosis of acute coronary syndrome, identification of heart failure status through remote patient monitoring	
	Radiology	Mammography, diagnosis of pneumonia from chest x-ray	
Electronic health records analysis		Identification of sepsis in the emergency department, Identification of breast cancer symptoms, Heart failure case identification, Identification of patient phenotype from analysis of intensive care unit data, identification of medical subdomains in clinical notes	
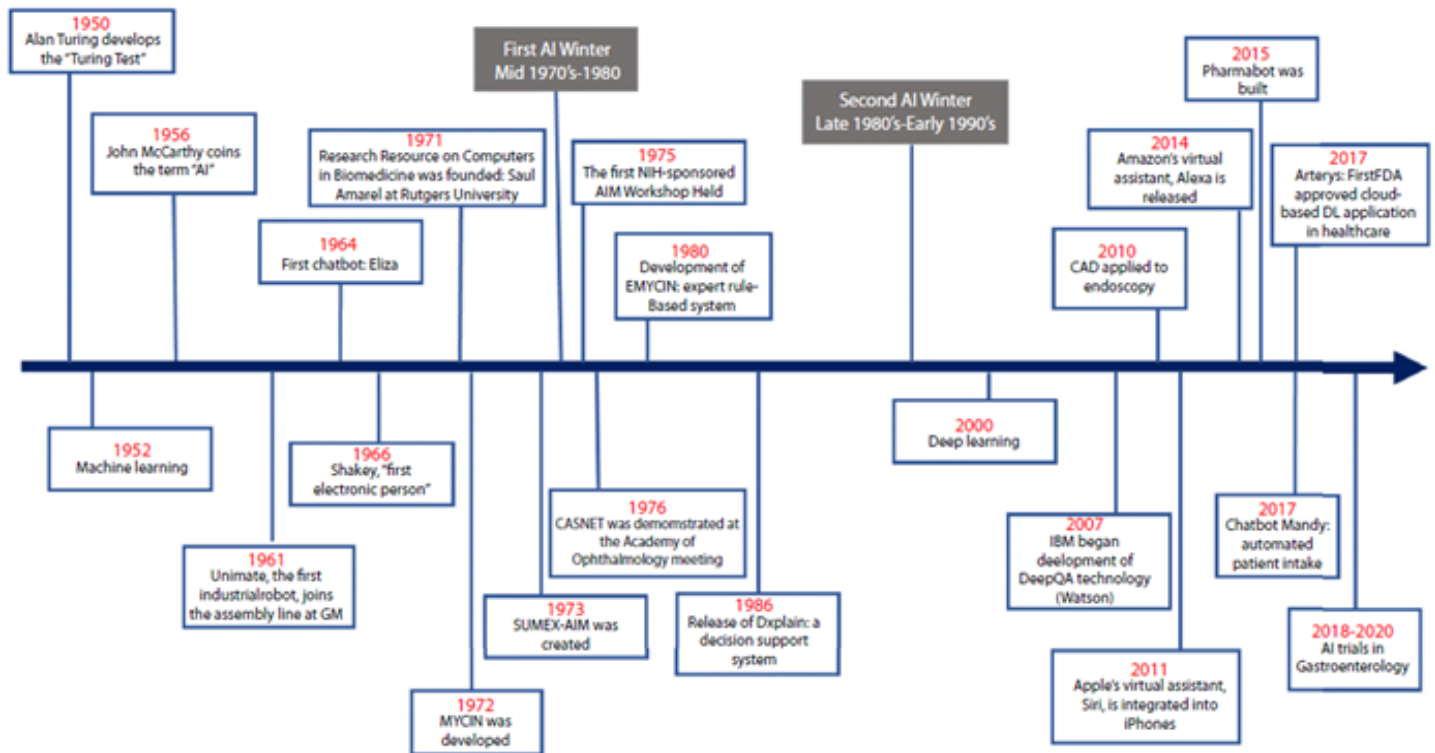
FIGURE 8. Historical evolution of artificial Intelligence.[30]

BCT or DLT

Patients and healthcare practitioners are faced with the challenge of accessing, managing, integrating, and sharing health records securely.[52] In many countries data are recorded on legacy papers and numerous disconnected electronic systems. In the US, 90% of physicians use unconnected computerized systems. Patients must recount their history multiple times, which may be done incompletely. Medical errors are estimated to be the third leading cause of death for Americans. In 2015, 140 million patient records were breached according to Protenus Breach Barometer Report.[53] The WHO estimates that many countries in Africa and parts of Asia and Latin America have areas where more than 30% of the medicines on sale can be counterfeit.[54]

In 2018, the healthcare industry continued to be plagued by data breaches involving sensitive patient information. According to the Breach Barometer 2019 Report, more than 15 million patient records were breached in 2018. Such incidents allow blockchain vendors to launch new solutions.[54]

To alleviate the associated adverse effects, an interconnected system is needed. In the UK, the NHS planned to interconnect all computerizing health network records by 2018; however, this target was delayed first to 2020 and again to 2023.[55] Nevertheless, during COVID-19, which is ravaging the globe, blockchain technology was used by two UK hospitals to keep tabs on the storage and supply of temperature-sensitive COVID-19 vaccines.[56]

In March 2021, Moderna, a biotechnology and pharmaceutical company based in the United States, signed a new agreement with IBM to use blockchain technology to manage its COVID-19 vaccines. Additionally, 3M Pharmaceuticals, another American pharmaceutical giant, uses blockchain technology to curb counterfeit pharmaceuticals. Recently, it has started using blockchain technology to identify and stop counterfeit face masks.[57]

BCT, though initially designed for the financial market, its inherent characteristics make it suitable for the health sector, insurance, pharmacy, IoT, food science, industries, e-voting, tourism, energy, and legal contract.[58-60] BCT helps streamline business processes by establishing trust, accountability, and transparency.[58] In medical applications, the ideal blockchain model would be scalable with high security and data privacy. In finance, bitcoin and Ethereum are examples of cryptocurrencies that use blockchain technology.[61]

In medical and clinical services, by using BCT, patients become the platform, owning and controlling access to their healthcare data. The data are stored in the private blockchain cloud, where they cannot be changed by anybody, including physicians and patients themselves internally and natively.

Because data is stored on a decentralized network, there is no single institution that can be robbed or hacked to obtain a large number of patient records. Data is encrypted in the blockchain and can only be decrypted with the patient's private key. Even if a malicious party infiltrates the network, there is no practical way to read patient data.[62,63]

In terms of patients' full control of their health record history, there are three major aspects of privacy that need to be considered: (a) data ownership; (b) fine-grained access control; (c) data transparency, integrity, and auditability.[53]

In healthcare services, the key enablers of blockchain are the need for patient data security, desire to reduce medical errors and mistakes, breakthroughs in genomics, drug traceability and safety, government partnerships, removal of unscrupulous attacks, reduction of cost in medical transactions, and improved confidentiality in healthcare business operations.[63]

A blockchain is a ledger of transactions where an identical copy of the ledger is visible to all the members of a computer network. It is a digital healthcare system management from which authorized users, such as providers and patients, have access.[62] BCT is a permanent record of online transactions distributed, shared, and maintained by multiple parties.

The first blockchain was developed by Satoshi Nakamoto in 2009. The technology brought breakthroughs until 2021 when Dubai hosts all government operations and record-keeping operations on blockchain as part of the Smart Dubai 2021 initiative.[64]
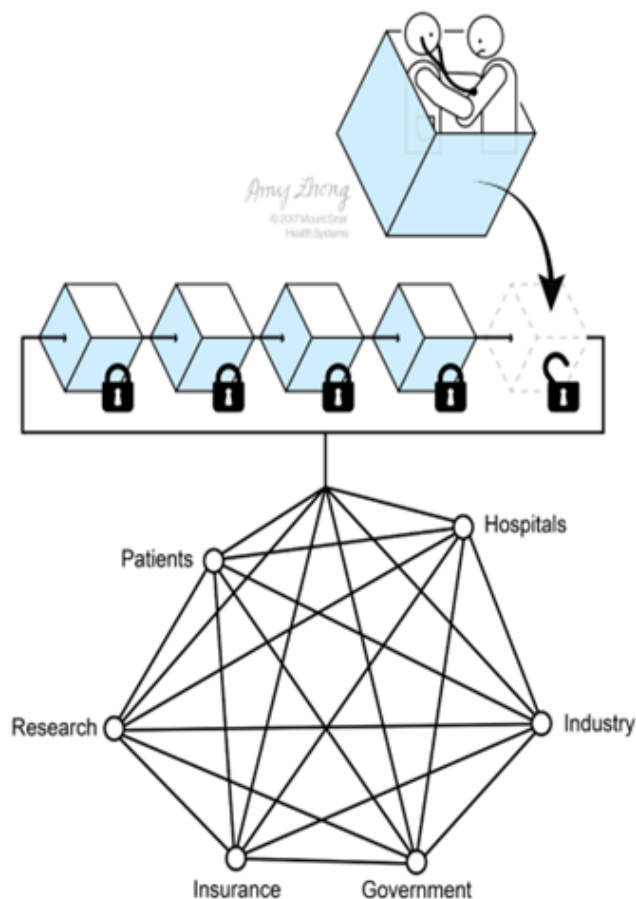
FIGURE 9. Theoretical schematic of blockchain technology in healthcare.[59]

The data-sharing practice is essential to enable clinical practitioners to transfer their patients' clinical data to the concerned authority for a quick follow-up.[60] BCT differs from a personal ledger in the number of security checks, whereby a blockchain makes many security checks.[61] This technology is interpreted as blocks linked together to form a chain to offer patients and caregivers the ability to securely share the patient identity and healthcare information across platforms.

Today, the market for blockchain technology is very promising because it is forecast to save $100 billion per year since 2025. The saving will be realized in a reduction in data-breaching related costs, operations costs, information technology (IT) costs, counterfeit-related fraud, and insurance fraud.[52] In healthcare, the blockchain market in healthcare was valued at USD 2.12 billion in 2020 and is expected to reach USD 3.[49] billion by 2026 and USD 4.7

billion in 2027 with a CAGR of 8.7% during the forecast period, 2021–2026, with North America as the fastest-growing market.[54] Regarding research, the number of scientific publications about blockchain technology shifted from 5 in 2016 to 64 in 2018. This was another indicator that this market was rapidly attracting researchers.[65] In its structure, the components of blockchain technology are listed below.

- **Blocks** are the base of a blockchain and contain records linked lists, chains, genesis blocks, and consensus protocol.[66] Blocks contain records of the past transactions and have segments reserved to save the data for future transactions. A block on a blockchain network consists of hash codes, root hash of merkle tree, and nonce.[61]

- **Chains** are blocks inside a blockchain network that are connected to each other. Multiple blocks that are joined together form a chain of blocks.

- **Nodes** contain the entire history of a blockchain network. Nodes are the devices that store these vast amounts of data. Computers, laptops, and big servers function as nodes. All the nodes in a blockchain network are linked together. Nodes verify the signatures, double-check the answer of the hash code after authenticating the details, and add a new block to the blockchain network. Nodes can stay both online and offline.[61]

- **Master nodes.** Selective blockchain networks have master nodes which are are more capable than normal nodes.[61]

- **Peer-to-peer networks (P2P)** are networks designed for linking two nodes.

There are four types of blockchains:

- **Public blockchains** are permissionless blockchains that allow anyone to join. All nodes of the blockchain have equal rights to access the blockchain, create new blocks of data, and validate blocks of data.[58,67]

- **Private or managed blockchains** are permissioned blockchains controlled by a single organization. In a private blockchain, the central authority determines who can be a node. The central authority also does not necessarily grant each node with equal rights to perform functions.[67]

- **Consortium blockchains** are permissioned blockchains governed by a group of organizations, rather than one entity. However, setting up consortiums can be a fraught process as it requires cooperation between several organizations presenting logistical challenges and potential antitrust risks.[67]

- **Hybrid blockchains** are controlled by a single organization, but with a level of oversight performed by the public blockchain, which is required to perform specific transaction validations.[67]

Some key players in the blockchain market are IBM Corporation, Microsoft Corporation, Gem, Patientory Inc., Guardtime Federal, Isolve, and Factom[57]

TABLE 5. Challenges of Blockchain Technology[59,62,60]

Technology	Blockchain software is still in its infancy, continually being developed and refined
Integration	Must initially be co-existent with current technologies, must be integrated overtime
Cost	Adoption of new technologies will incur initial greater costs to institutions
Regulation	Government institutions have yet to settle regulatory concerns over blockchain technology
Culture	Adoption of the technology will require significant buy-in from the global community
Energy	Maintaining the blockchain requires a network of nodes, and resulting substantial computing power
Privacy	Emerging cyber security concerns must be addressed before individuals will entrust data to a public blockchain

Robotics Technology

Technological advancement has revolutionized how medical procedures take place, including surgical operations. Credits go not only to the development of actuators, sensors, control systems, and materials but also to the growth of imaging systems for medical applications such as higher resolutions and magnetic imaging.[71] Apart from the industrial robot (a word originating from the Czech word "robota" meaning compulsory labor) first developed 50 years ago, today's medical and healthcare robots are used in tremendous clinical work.[72, 73]

According to the Robotic Institute of America, a robot is a machine in the form of a human being that performs the mechanical functions of a human being but lacks sensitivity. The first robot was developed by Leonardo Da Vinci in 1495, purposed at amusing royalty. It was followed the creation of the first operational robot by Joseph Marie Jacquard in 1801, in which an automated loom, controlled by punch cards, created a reproducible pattern woven into cloth.[73]

In medicine, robotic systems were first introduced in the mid-80s, and today they make an impact in various medical disciplines, including general surgery, research, therapy, rehabilitation, neurosurgery, orthopedic surgery,[74] and medical transport (for example, TUG Robot able to carry around more than 400 kilograms of medication).[75]

As per 2017, 20% of the world population experience difficulties with physical, cognitive, or sensory functioning mental and behavioral health, which can be solved with robotics technology application.[76] The very first mechanical robot to be used in surgery was the Puma 560 in 1985 for the precise positioning of the cannula for brain biopsies.[77]

Statistics show that 1in every 25 patients will contract hospital-acquired infection (HAIs) in the USA, and 1 in 9 will die.[75] That is why next-generation smart hospitals have robotics that can help reduce infections, viruses, and bacteria.[78] For example, Xenex Robot allows for fast and effective systematic disinfection of any space within a healthcare facility by destroying deadly microorganisms causing HAIs using special ultraviolet (UV) disinfection methodology.[75] Data from the USA show that surgery costs annually are estimated to be $170 billion, with an estimated $41 billion US spent on readmission due to complications. In Europe. over half (52%) of all surgeries were due to unexpected complications. Consequently, robotics can lower the readmission rate by up to 50%, resulting in a saving of $10 billion annually.[79] The global landscape of robotics application in healthcare and well-being are presented in Table 7.
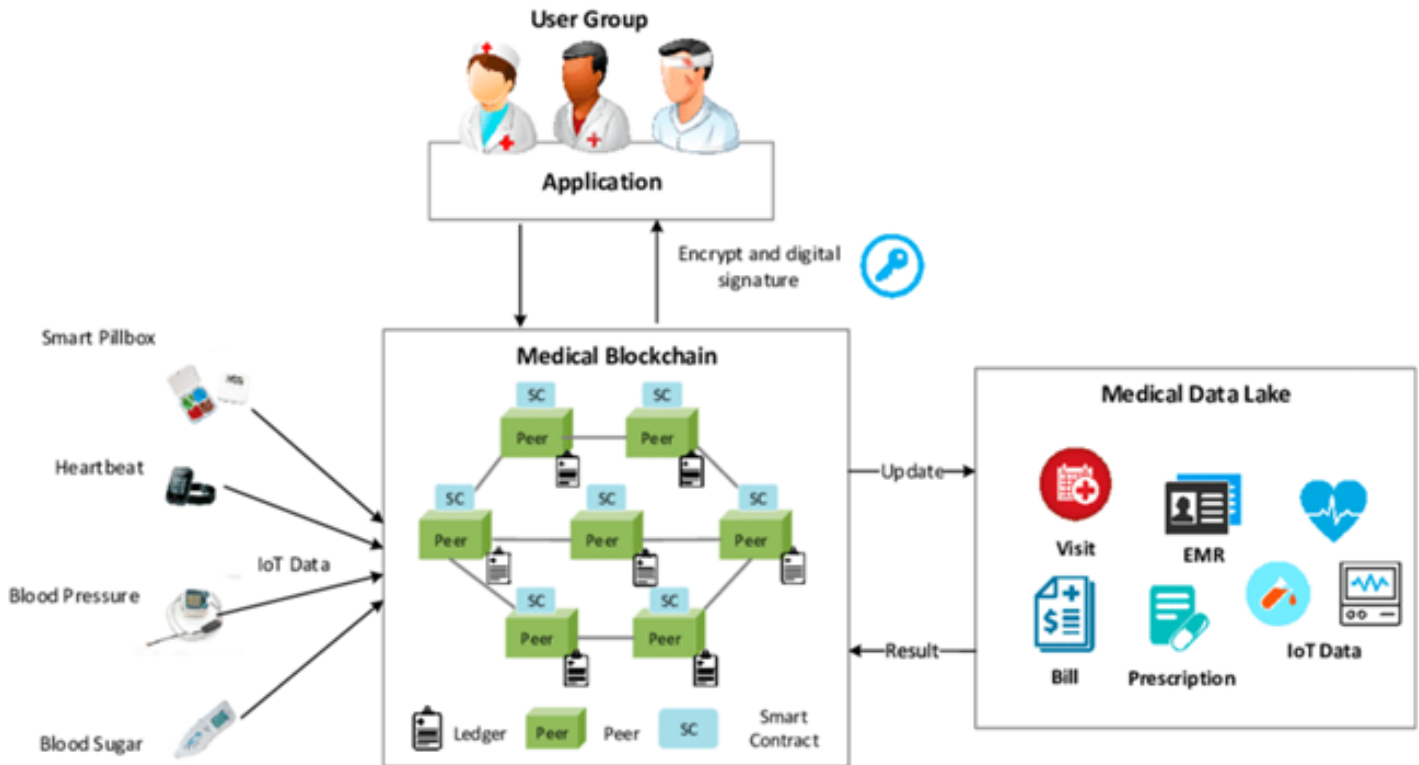
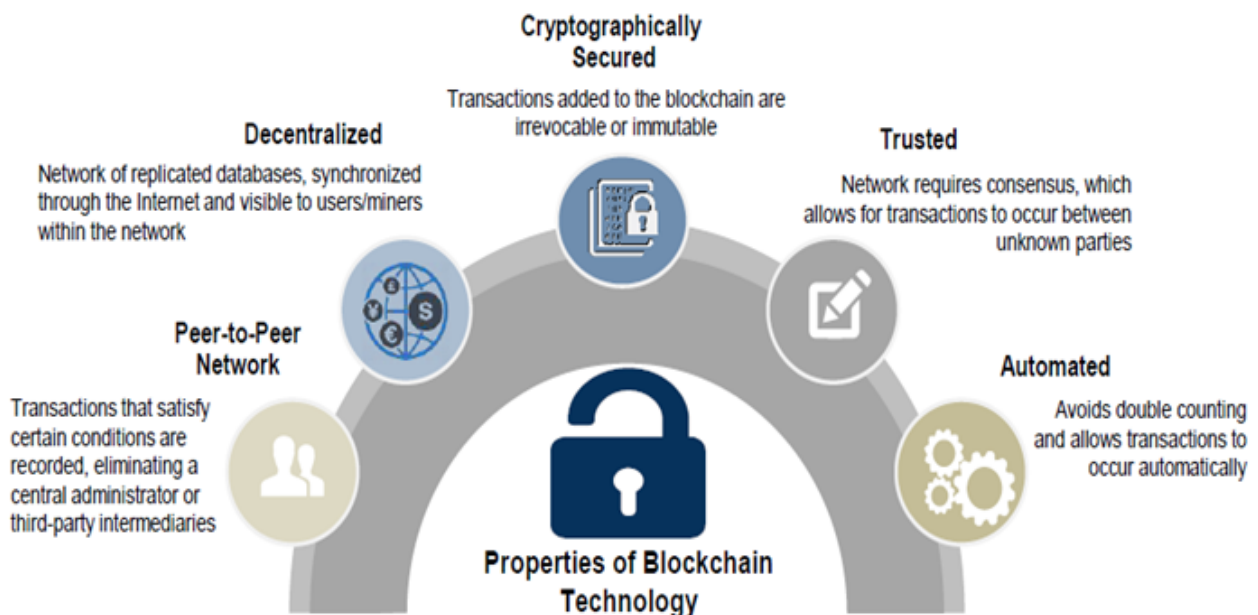**FIGURE 10.** Blockchain structure in hospital applications.[68]

FIGURE 11. Properties of blockchain technology.[69]

TABLE 6. Blockchain Potentials for Healthcare and Life Science[52,59,70]

Category	Potential use	Key Benefits
Patients	Patient empowerment. Patients can keep track of their medical background. Patients can check their latest medical prescriptions, Patients can share their data securely across their providers	Increases patient trust. Improves patient access to trusted data. Facilitates better collaboration, Increases transparency. Improves and personalizes the patient experience. Increases efficiency and reduces operations costs, Enables patient access to their health records anywhere in the world. Enables patient access to their latest prescriptions
Regulation and compliance	Compliance tracking, Smart contract-based check	Establishes a trusted audit trail verifiable in real-time. Establishes a platform to enforce privacy regulations automatically. Enables monitoring of who has shared data and with whom, without revealing the data itself
Inter-company processes	Transfer of funds. Medical devices supply chain. Temperature-controlled supply chains, Services	Facilitates automated payments through smart contracts. Increases speed for payments. Provides full transparency of assets across the supply chain to the patient. Enables certified & private messaging between medical devices and service providers. Brings all transactions into a single platform
Administration and back offices	Revenue management	Improves efficiencies in tracking and tracing areas where leakage occurs. Reduces admin costs, Increases reliability and auditability. Speeds up financial transactions process
Pharmaceuticals	Verifies drug provenance. Creates an industry-wide, single source of aggregate information	Tracks and traces pharmaceuticals, Proof of authenticity for anti-counterfeiting techniques. Helps prevent the transport and sale of counterfeit products. Makes it is possible to detect the full spectrum of complications related to pharmaceutical treatment
Research and development	Securing clinical trials	Prevents theft of intellectual property. Enables users to authenticate any document and ensuring proof of the existence. Enables access to a huge anonymous and authenticated database of patients

In their general design and construction, medical robots consist of a Central Processing Unit (the robot's brain for coordinating all its activities) and Sensors (acting as the powerhouse of the robot feedback mechanism). These include light sensors, sound sensors, temperature sensors, contact sensors, proximity sensors, distance sensors, pressure sensors, positioning sensors, etc.). Also included are Actuators (the robot's hydraulic, pneumatic, or electric muscles), End-Effectors (the tools that perform the actual work and interact with the environment or a workpiece), the Power Supply (energy required for robot operation), and the Program (for providing the logic that drives the robot behaviors and activities).[81]

Robotics applications in medicine involve different stakeholders, including primary stakeholders (direct robot user, clinicians, and caregivers), secondary stakeholders (robot makers, environmental service workers, health administrators), and tertiary stakeholders (policy makers, insurers, advocacy groups).[76] Among robotics applications, surgical robots have a high revenue growth market segment, are highly competitive with established players, well-defined market entry routes, and a good product innovation pipeline.[80]

In 2020, the leading global company in medical robotics was Intuitive Surgical, with a market cap of $121 billion, 6335 robots in service,[78] with more than 1.2 million procedures performed globally, and with a growth of 18% per year.[80]

TABLE 7. Medical Robotics Market Potential Assessment Summary[80]

Healthcare robotics		Technology Readiness level	Breadth of application	Current adoption	Growth potential
Medical robots	Surgical Robots				
	Diagnostics Robots				
Healthcare Service robots	Medication delivery and dispensing				
	Cleaning and disinfecting				
	Telepresence and remote monitoring				
	Autonomous vehicles				
Care robots	Personal assistant/ Companion robots				
	Assistive robots				

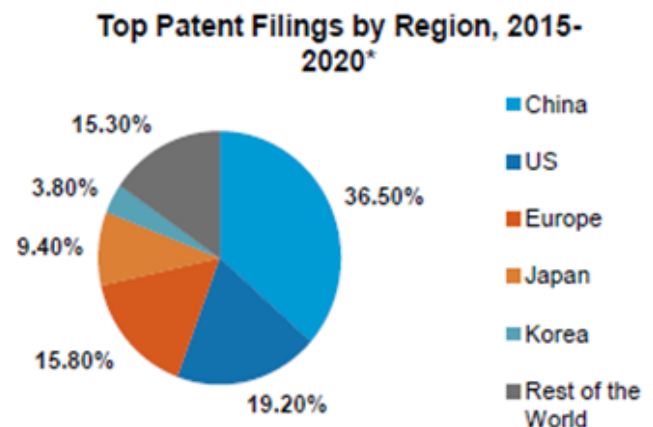| Predominantly R&D and prototype phase → Several Commercial Products **Technology Development**	Low, Specific → High, Multiple **Breadth of Applications**	Low, Pilots → High, Commercial **Current Adoption**	Low → High **Growth Potential**

Other companies in service include Boston Dynamics, Stryker, Accuracy, Vicarious Surgical, Medtronic, GE Healthcare, Myomo, Stereotaxis, Ottava[77,78] Neocis.Inc, Medtronics, Brainlab, Smith & Nephew plc, Corindus Vascular Robotics, Inc., Riverfield Co., Ltd, Auris Health, Inc., etc.[80]

Between 2015-2020, China emerged as a leader for next-generation surgical robotic systems' innovations with 237 (36.5%) patents published in this area from 2015 to 2020 (Figure 12).[80]

Top Patent Filings by Region, 2015-2020*

- China 36.50%
- US 19.20%
- Europe 15.80%
- Japan 9.40%
- Korea 3.80%
- Rest of the World 15.30%

FIGURE 12. Medical robotics patent filings from 2015 to 2020.[80]

The global medical robot market is expected to reach USD 12.7 billion by 2025 from an estimated USD 5.9 billion in 2020 at a CAGR of 16.5% during the forecast period. On the other hand,82 medical robotics market is forecast to account for $43.22 billion in 2028 with a compound annual growth rate of 22.3% from 2021 to 2022 (Figure 13).[82]
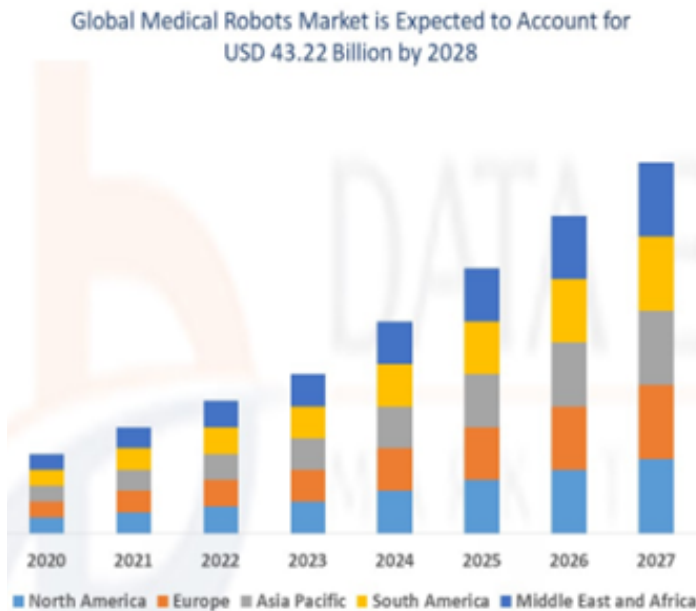
FIGURE 13. Market growth for medical robotics.[82]

The key drivers of medical robotics market evolution include demand for minimally invasive procedures for diagnosis, improved precision in diagnosis and treatment, technological advancement in AI, management of surge capacity during peak demand, and improvement of the overall efficiency of logistics. Also, there is a desire to increase the automation of pharmacy operations, large population living with chronical illnesses, hospitals' will to maintain hygiene protocols and standards, especially as it directly impacts hospital accreditation, reduces manual labor, improves efficiency and cost savings for cleaning and disinfection. Increasing prevalence of stroke, multiple sclerosis, Parkinson's disease, cerebral palsy, Rise of the elderly population, and shortage of caregivers.[80]

Nowadays, since 2019 when the whole world experienced the COVID-19 outbreak, robotics has been finding applications in undertaking human-like activities.[83] In Rwanda, robots were deployed to minimize contact time with confirmed cases and reduce the risk of contamination of health professionals in COVID-19 treatment centers. The 5 human-size robots are programmed to perform temperature screening, take vitals readings, deliver video messages, detect people not wearing masks, and then instruct them to wear masks properly. One robot called Urumuli deployed at Kigali International Airport had the capacity of screening 50 to 150 people per minute and reporting abnormalities to officers on duty.[84]

Later, on 9 February 2021, in partnership with the United Nations Development Programme, the government deployed another set of three THOR UVC robots to Nyarugenge District Hospital to strengthen the national response to COVID-19 pandemic.[85] Robots were also used to store patients' data during diagnosis and treatment, reduce the workload of healthcare providers, ease the diagnosis procedures, and assist the physicians and students in learning more about the new disease in a short time.[86]

In South Korea, a self-driving robot with cameras and an LED screen was used to greet clients at the country's biggest mobile operator, check their temperatures, dispense hand sanitizers, and disinfect the floor. Other robots were used to disinfect 33 square meters in 10min using ultraviolet radiation. In addition, they could detect people's gatherings, advise them to disperse, and wear face masks.[87] In China, Wuhan City, where the pandemic was first detected, constructed a fully robot-staffed hospital where patients entering were screened by connected 5G thermometers to alert staff for feverish. In addition, Patients wore smart bracelets and rings that synced with Cloud Minds' AI platform so their vital signs, including temperature, heart rate, and blood oxygen levels, could be monitored. Doctors and nurses also wore the devices to catch any early signs of infection.[88] Regarding the future of medical robotics, up to 2013, Nanorobotics was still the largely hypothetical technology of creating machines or robots at or close to the scale of a nanometer.[73]

Though the growth of the medical robotics industry is promising, it is humped by the following challenges: high establishment cost, fewer trained professionals to administer the tests, technical complexities leading to operational issues, the high running cost for disadvantaged people.[80]

Nanomedical Technology

It is a technology for diagnosing, treating, and preventing disease and traumatic injury, relieving pain, preserving and improving human health using molecular tools and molecular knowledge of the human body.[89] Nanotechnology classically refers to the matter in a size range of 1–100 nm but can be extended to include materials below 1 μm in size.[90] Nanomedicine is also defined as the application of nanobiotechnologies to medicine.[91,92]

Though the concept of nanotechnology dates to 1959, the optimistic expectation of nanoparticles and nanoscale tools to improve the diagnosis and pharmacological treatment of several diseases was first established in 1990.[93] The basis of this new science derives from the development of an array of ultramicroscopic devices and the studies of cellular, molecular, and finally atom-sized structures in biology, chemistry, and physics in the 20th century. Nanotechnology is not in itself a single emerging scientific discipline, but rather a meeting of different traditional sciences linking physics, chemistry, biology, medicine, electronics, and IT.[94] Nanotechnology in medicine was recently focused on because there is a diversity of diseases originating from the alteration in biologic processes at the molecular level like mutated genes, misfolded proteins, and infections caused by viruses or bacteria (Figure 14).[95] The three main subsections of nanomedicine are: nanobiotechnology, nanotechnology, and nanobiomimetics.[96]
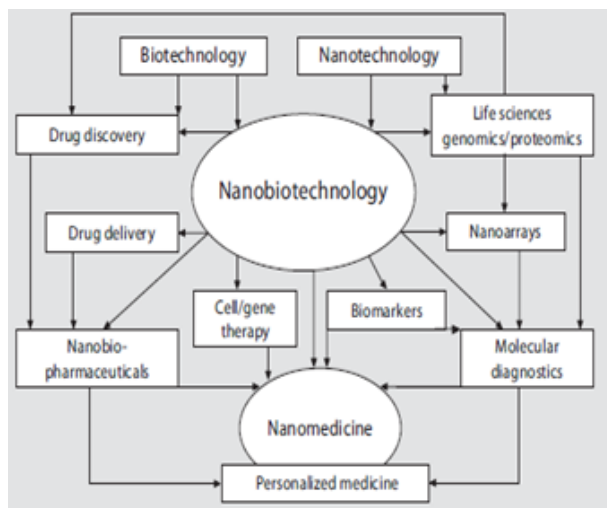
FIGURE 14. Relationship of nanobiotechnology to nanomedicine and other biotechnologies.[91]

Currently, in medicine, nanotechnology is used in antibacterial treatment, wound treatment, cardiovascular diseases, ophthalmology, cancer-fighting, cell repair, imaging, probing of DNA structure, tissue engineering, tumor detection, separation and purification of biological molecules and cells, MRI contrast enhancement and phagokinetic studies, company directory and to deliver drugs, heat, light or other substances to specific types of cells (such as cancer cells).[91,97] Its use in diagnostics is at the development stage. The use of nanoparticles will reduce damage to healthy cells in the body and contribute to the early detection of diseases.[91] The global Nanomedicine market size is projected to reach USD 232 million by 2026, from USD 150 million in 2019, at a CAGR of 6.4% during 2021-2026.[98]

The nanomedicine market segmentation by type includes:

- Quantum dots (QD): QD are semiconductor nanocrystals that have a reactive core (made of cadmium selenide CdSe, cadmium telluride [CdTe], indium phosphide [InP], or zinc selenide [ZnSe]), for controlling their optical properties. QD are used in medical real-time tissue imaging,[99] biological probes, for live cells labelling,[100] drug delivery vehicles, in vivo imaging, therapeutic delivery,[101] blood cancer assay, and cancer detection and treatment, in vivo animal targeting, tracking different particles, forecasting of disease stage.[102]

- Nanoparticles: A considerable fraction of the solid matter on earth can be found in the size range of colloids and nanoparticles, and in the last 2 decades, scientists have shown that colloids and nanoparticles are present everywhere in the environment.[103] NPs are categorized into three types: natural nanoparticles, incidental nanoparticles, and engineered nanoparticles (Figure 15).[104]

From a chemical point of view, nanoparticles are classified into inorganic and organic types. Inorganic nanoparticles are used as antimicrobial agent against bacteria, fungi, parasites, and viruses.[104] Organic nanoparticles prepared from various materials, including polymers and lipids, have found exciting therapeutic delivery and imaging applications.[105]
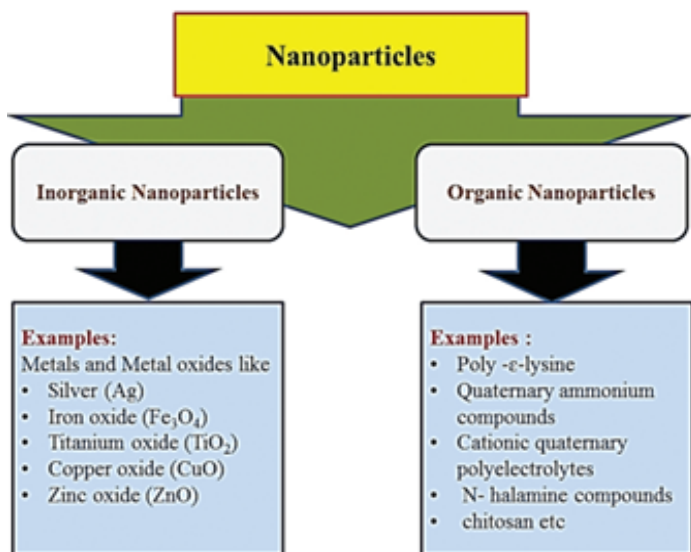
FIGURE 15. Types of nanoparticles.[104]

The choice of material impacts various properties, including drug encapsulation, immunogenicity, and targeting. At the same time, the design of nanoparticles, such as size, shape, flexibility, and compartmentalization, will also impact nanoparticle performance. These two attributes (choice of material and nanoparticle design) collectively determine the therapeutic outcome (Figure 16).[105]
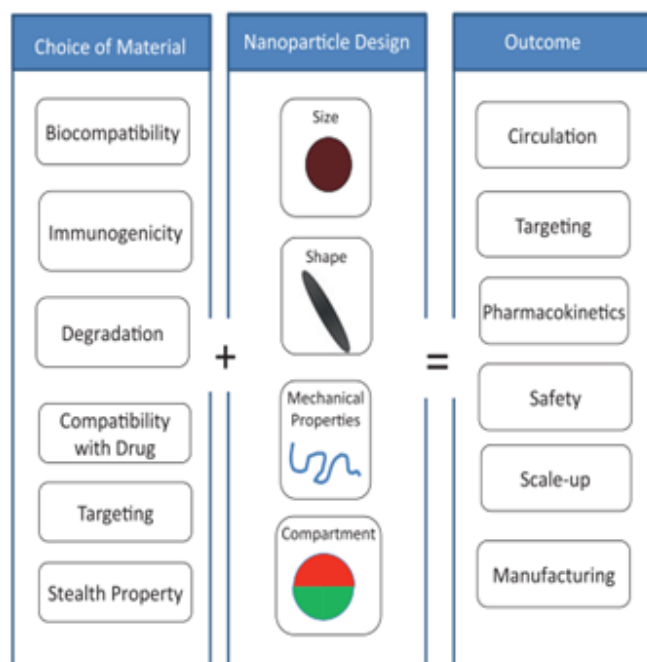

FIGURE 16. Design parameters for nanoparticles.[105]

Other applications of nanoparticles within medicine include tissue engineering, bio-micromechanical systems (bioMEMS), biosensors, anticancer drugs, microfluidics, and diagnostics.[106]

- **Nanoshells:** The discovery of nanoshells was made by Professor Naomi J. Halas and her team at Rice University in 2003.[107] These are a special class of nanomaterials that consist of concentric particles.[108] A nanoshell is a type of nanoparticle with a dielectric (e.g., silica) core and a thin metal coating (usually gold).[109]

Nanoparticles find a place in medicine because of their safety, biocompatibility, stability, bioavailability, optically tunable, and photo-luminescent ability as well as high ability to attach to many therapeutic materials. Nanoshells (and especially gold nanoshells) show promise application in biomedical imaging, target therapy, gene delivery, tissue welding, drug delivery systems, therapeutic applications in general, and cancer imaging and treatment (Figure 17).[110]
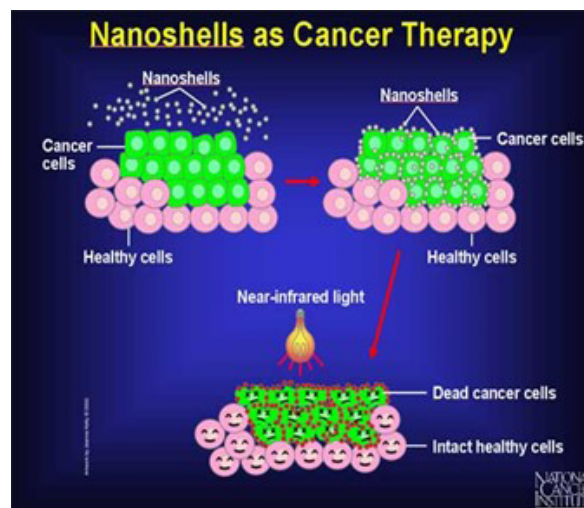
FIGURE 17. Use of nanoshells for cancer treatment (Source: National Cancer Institute).

Gold nanoshells exhibit unique optical properties because their interaction with the electromagnetic field is greatly intensified by a phenomenon known as localized surface plasmon resonance. They are designed to absorb radiation at various frequencies absorb certain types of radiation. Once the nanoshells are attached to the cancerous cells, only laser light is needed to treat cancer. Near-infrared (NIR) light passes through the body

and reaches the gold nanoshell. The tuned gold nanoshell receives the NIR light and converts the light energy into heat, killing the cancer cells.[107]

- **Nanotubes:** Nanotubes, usually made in carbon (CNTs), consist of carbon atoms arranged in a series of condensed benzene rings rolled up into a tubular structure.[111] Carbon nanotubes (CNTs) are cylindrical molecules that consist of rolled-up sheets of single-layer carbon atoms (graphene). They can be single-walled (SWCNT) with a diameter of less than 1 nanometer (nm) or multi-walled (MWCNT), consisting of several concentrically interlinked nanotubes, with diameters reaching more than 100 nm. Their length can reach several micrometers or even millimeters (Figure 18).[112]
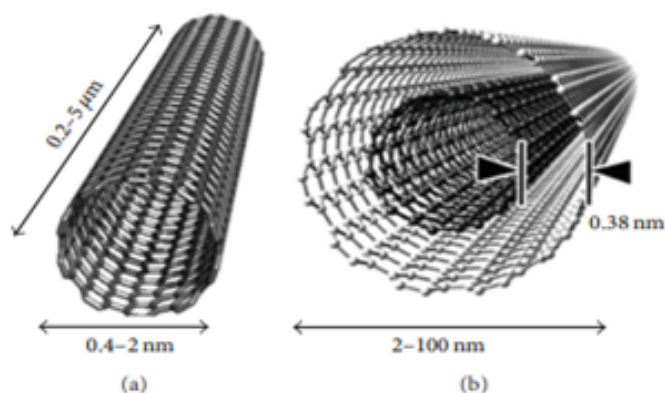
FIGURE 18. Conceptual diagrams of single-walled carbon nanotubes (a) and multiple-walled carbon nanotubes (b).[111]

Their impressive structural, mechanical, and electronic properties are due to their small size and mass, incredible mechanical strength, and high electrical and thermal conductivity. In medicine, nanotubes are used in pharmaceuticals, drug delivery systems, gene delivery and therapy, tissue engineering, bio-imaging, biosensor applications, lab-on-chip devices, photo-thermal therapy, diagnostics, and high-performance composites for implants.[113,114]

Although there are advantages of nanotubes (like biocompatibility, rigidity, mimicking of natural tissue nanofibers, stimulating the adhesion and proliferation of cells and ability to form strong 3-D architectures, high surface area, high photo-stability and absence of quenching, special optical, mechanical, and electronic

properties),[114] concerns related to their toxicity, biosafety, and biodegradation still remain.[113] Examples of nano-technology equipment in medicine include atom probes, atomic absorption spectrometer, profilometers, raman microscopes, calorimeters, cryogenic probe stations, scratch testers, flow chemistry reactors, graphene, surface analyzers, Spectroscopic ellipsometer, wafer bonders, x-ray detectors, x-ray diffractometer, etc.[106]

The challenges faced by nanotechnology include high manufacturing costs, technical challenges, raised skeptical opinions within the scientific community about the clinical relevance of nanomedicine.[93] The competitive landscape of the industry has also been examined along with the profiles of the key players who include Abbott Laboratories, Arrowhead Pharmaceuticals Inc., General Electric Company, Luminex Corporation, Merck & Co. Inc., Nanobiotix, Novartis AG, Pfizer Inc., Sanofi SA, Starpharma Holdings Limited.[115]

Telemedicine and Telehealth

The provision of primary healthcare has been challenging during the recent and current periods of COVID-19 due to overcrowding of medical services seekers to different health facilities.[116] It is evident to many that COVID-19 accelerated the adoption of Telemedicine globally.[117] Telemedicine uses electronic communications and information technologies to provide clinical services when participants are at different locations.[118,119] Some writers prefer to use the term "telehealth" interchangeably with "telemedicine," but Telehealth is broader because it also considers even non-clinical services. Telehealth refers to 'the use of telecommunications and IT to provide access to health assessment, diagnosis, intervention, consultation, supervision and information across distance.[120]

Telemedicine is traced back many centuries, starting from ancient hieroglyphs and scrolls to share information about health-related events such as outbreaks or epidemics. This was followed by using smoke signals to warn nearby cities of sickness.[120] In contemporary times, Telemedicine through telephone and video technology has been used since the 1960s in the military and space sectors.[121] Apart from military services, Telehealth was first used in 1972 when Murphy and Bird conducted 500

patient consultations via interactive television.[122] Today, Telemedicine is applied in radiology, dermatology, surgical peer monitoring, medication management, mental health, diagnosis, patient monitoring, etc.[123]

The drivers of Telemedicine include: enhancement of care coordination, patients and doctors are fascinated by the services offered by Telemedicine, society, and healthcare tendency to digital life (in OECD countries, nearly 65% of people aged 65 to 84 years are estimated to have more than one chronic condition, a prevalence that reaches 89% for those aged 85 and over), bridging of the rural gap, continuous innovation in the consumer technology market, projected shortages in the health professional workforce, growth of consumerism in health care cost-effectiveness, quick access to medical services,[123,124] improved quality, medication management, changes in care models.[125,126]

The services offered by Telemedicine include specialist referral services (assisting a general practitioner in rendering a Diagnosis), direct patient care (sharing audio, video, and medical data between a patient and a health professional for use in generating a diagnosis, treatment plan, prescription or advice), remote patient monitoring (devices to remotely collect and send data to a monitoring station for interpretation), medical education and mentoring, consumer medical and health information, patient support service (reminders to take medication, supervision, scheduling of appointments and similar applications which are not implicitly medical).[118]

There are four key elements needed for a successful telemedicine program.

1. Collaboration tools are devices that help patients to connect with healthcare service providers. They include smartphones, laptops, tablets, etc.[127]

2. Medical peripherals are the diagnostic tools used in Telemedicine, such as otoscopes, ultrasound machines, or digital stethoscopes.[127]

3. Workflow represents adequate software to manage the complete process of connecting patients to medical professionals and to integrate Telemedicine with their existing IT resources.[127]

4. Cloud-based services: Cloud computing delivers different services through the Internet. These resources include tools and applications like data storage, servers, databases, networking, and software. When using cloud computing, the user is not required to be in a specific place to access it, allowing the user to work remotely.[128] In Telemedicine, cloud-based services help user-friendly access to medical records for both clinicians and patients from anywhere they can access the Internet.[129]

When the world experienced COVID-19 pandemic, social distancing measures were put in place to fight its sustainability. Moreover, the rapid global spread of CO-VID-19 has increased the volume of data generated from various sources.[130] The cloud technology had a major role in fighting the epidemic; it became a salvation for governments and organizations in numerous fields of life, education, health, industry, communication, remote surveillance, and more information (Figure 19).[131]
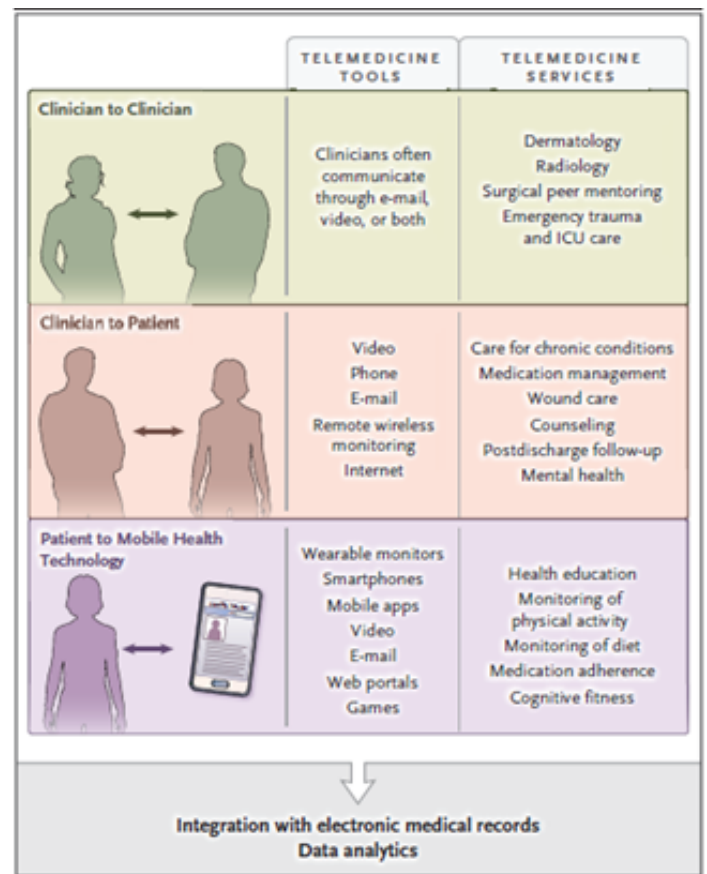

FIGURE 19. Use of Telemedicine by doctors and patient benefits.[123]

Generally, the lines of action of the telehealth program are based on three components, as presented in Figure 20.
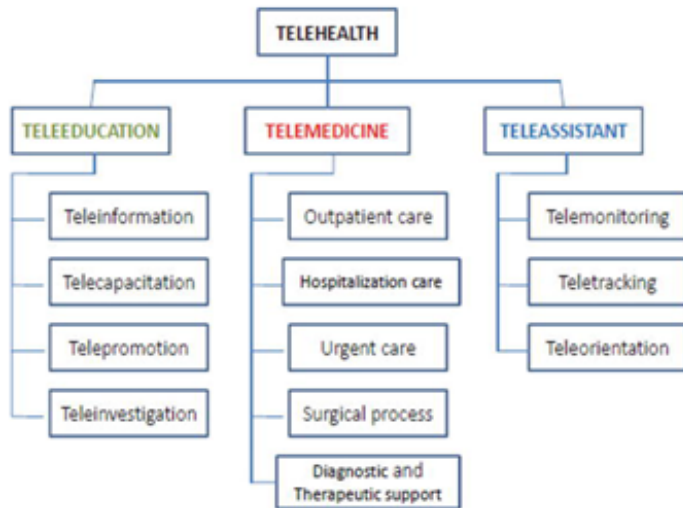

FIGURE 20. General lines of action of telehealth.[132]

From 2010 to 2017 the world experience growth in the use of Telemedicine, with three diseases dominating the growth rate. Those are diabetes, congestive heart failure (CHF), and chronic obstructive pulmonary disease (Figure 21).
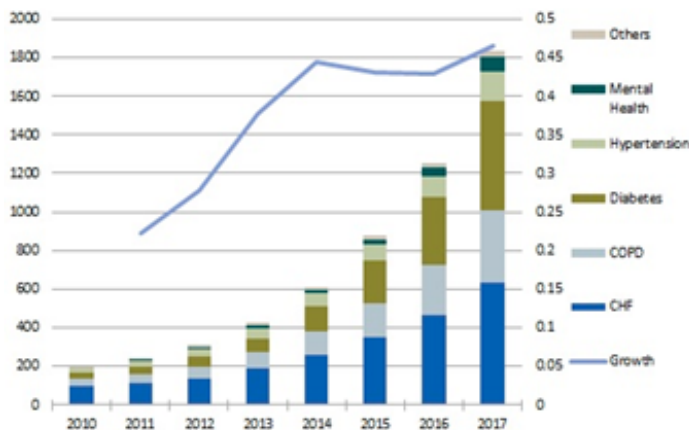

FIGURE 21. World Telehealth Patients (thousand) per disease.[133]

Since 2018, the quarterly investment in Telehealth has experienced peaks and bottoms, but when WHO officially declared COVID-19 as a pandemic on 13 March 2020, the investment in Telehealth has drastically increased compared to previous years, as presented in Figure 22.
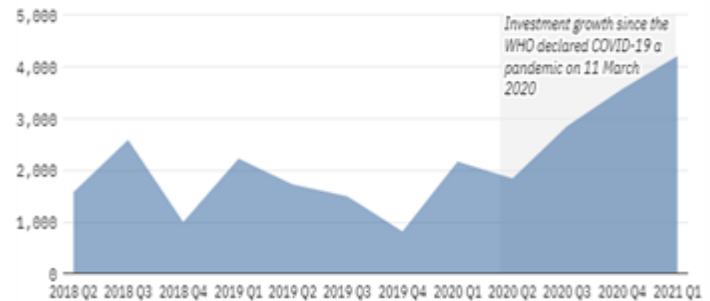

FIGURE 22. Quarterly global telehealth funding (2018-2021) in \$M.[134]

Generally, the global telemedicine market was valued at \$50 billion in 2019, with forecast potential growth to increase to \$460 billion by 2030.[135]

There are three types of Telemedicine:

- **Store and forward telemedicine or asynchronous Telemedicine.** In this type of Telemedicine, patient information such as medical images or bio-signals can be sent to the specialist as needed when it has been acquired from the patient.[136] It is regarded as the acquisition and storing of clinical information such as lab reports, data, images, sound, and videos that are then forwarded to (or retrieved by) another site for clinical evaluation.[122]

- **Real-time video or synchronous Telemedicine.** In this type of Telemedicine, consultations use video conferencing to connect the patient with the physician. Patients from their homes can use smartphones, tablets, or computers to interact with physicians. This method enables the physician to conduct a medical consultation as they would in person.[122]

- **Remote monitoring telemedicine.** This uses a range of technological devices to remotely monitor a patient's health and clinical signs. This is extensively used in the management of chronic diseases such as cardiovascular disease, diabetes mellitus, and asthma.[136]

The key challenges hindering the growth of Telemedicine are system development costs, digital literacy, Digital Technology Acceptance, less accurate diagnosis for specific images transmitted with Telemedicine concerning the original images, aspects linked to security and confidentiality in the doctor-patient relationship through

appropriate interfaces, and system implementation by the involvement of different parties.[132,137]

Although Telemedicine has many challenges to overcome, there are also opportunities to sustain its development. They include gap service coverage (for example, in the USA, teleradiology predominates other services), urgent service coverage (a case of a mobile telemedicine system for consulting acute stroke even remotely by employing a wireless LAN or a mobile phone network), and video-enabled multisite group chart rounds (model of medical education liked to clinical care).[138,139]

Big Data

The healthcare landscape is saturated with a large, diversified amount of data. Big Data in healthcare is over-whelming because of its volume and the diversity of data types, and the speed at which it must be managed.[140] Those data could be an enabling resource for deriving insights for improving care delivery and reducing waste.[141] Over more than a decade, as in other industries, the medical industry has experienced rapid digitization due to an increase in electronic medical records (EMR).[142]

Driven by mandatory requirements and the potential to improve the quality of healthcare delivery and obtain the best healthcare services meanwhile reducing the costs, requires a significant diversified quantity of electronic health records to help in clinical decision support, disease surveillance, and population health management.[140,143]

Big Data should be collected and used to ensure agreements between patients, healthcare service providers, and policy and research. Today, there is no common definition to explain what Big Data is. However, some researchers tried to formulate the meaning of Big Data. According to McKinsey the term "Big Data" refers to "datasets whose size is beyond the ability of typical database software tools to capture, store, manage, and analyze."[144] Big data is unmanageable using traditional software. We need technically advanced applications and software to employ fast and cost-efficient high-end computational power to utilize it properly. The term Big Data is described by the following characteristics: value, volume, velocity, variety, veracity, and variability, denoted as the 6 "Vs".[143]

According to some studies have shown that 93% of healthcare organizations have experienced a data breach because personal data is extremely valuable and profitable on the black markets, and this pushed organizations to start using data analytics to help them prevent security threats by identifying changes in network traffic, or any other behavior that reflects a cyber-attack.[146]

Big Data help to identify individual and community trends and develop better treatment plans or predict at-risk patients, forecast patient admissions trends and schedule the correct number of staff, drive innovation, compare chronic disease and population growth in neighborhoods, streamline insurance claims processes, easy detection of fraud and inventory tracking.[147] The global health data in 2013 only was estimated to be 153 Exabytes, with forecast potential growth to 2,314 Exabytes in 2020 alone.[135]

Big Data analytics are divided into four categories:

- **Descriptive analytics.** This consists in decrying the current situation and reporting on it.
- **Diagnostic analytics** aim to explain why certain events occurred and what factors triggered them.
- **Predictive analytics.** This reflects the ability to predict future events; it also helps identify trends and determine probabilities of uncertain outcomes.
- **Prescriptive analytics**. This proposes suitable actions leading to optimal decision-making.148

The global Big Data analytics in healthcare market size was valued at $16.87 billion in 2017 and is projected to reach $67.[82] billion by 2025, growing at a CAGR of 19.1% from 2018 to 2025.[149]

The nine stages that make analyzed data useful are shown in Figure 23. Big Data come from clinical practices and research, patient-generated data, medical claims, electronic healthcare records, social media, patient summaries, genomic and pharmaceutical data, clinical trials, Telemedicine, mobile apps, sensors, and information on wellbeing, behavior, and socio-economic indicators.[142,144] Big Data are used in medical services to gain advantages as shown in Figure 24, and Big Data architecture for healthcare is presented in Figure 25.
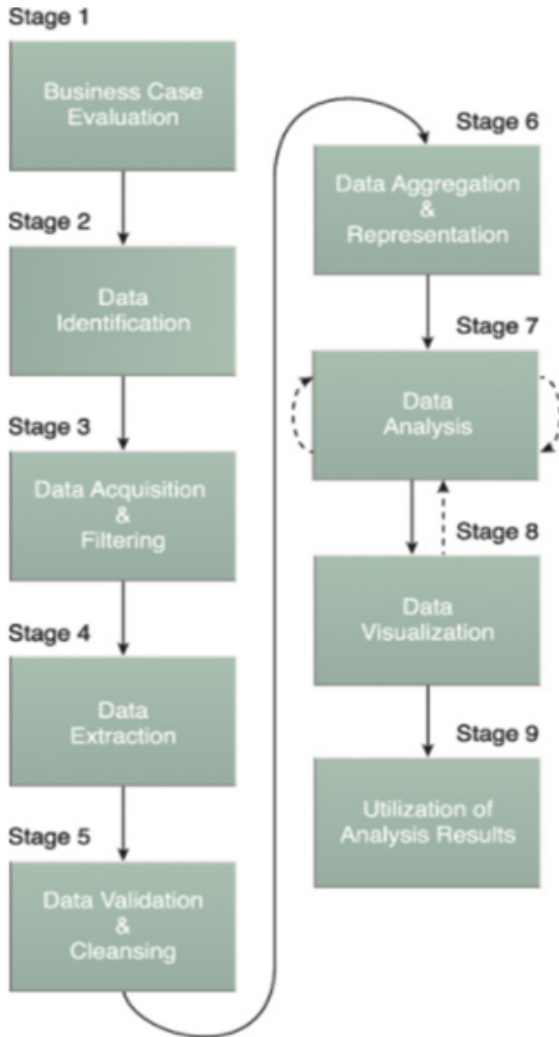
FIGURE 23. The nine stages of the Big Data analytics lifecycle.[150]

FIGURE 24. Application areas of Big Data technology in medicine.[146]

The Big Data analysis ensures that the health facility manager sees a big picture of the hospital, the attendance, its nature, the costs incurred, etc., which will help run it smoothly. An example of a dynamic dashboard for patient care is shown in Figure 26.[146] The challenges facing Big Data technology are: segmentation of data in healthcare providers (clinical data, financial data, administrative data, patient data are not linked and shared), protection of patient's privacy,[151] data capturing, cleaning and storage, stewarding and querying.[152,153]

There are several challenges in adopting Big Data technology: data in many health care providers are often segmented or siloed, complicated use Big Data is complicated, long system response time.[151,154] The key players

in healthcare data analytics include IBM, Cerner, Health catalyst, McKesson, Oracle.[155]

CONCLUSION

In conclusion, driven by needed increases in medical productivity, the growing prevalence of chronicling diseases, the increasing aging population, and the increasing emphasis by healthcare agencies towards early diagnosis and treatment, many countries and healthcare providers are struggling to scale-up technology level to provide adequate services to patients. In addition, physicians themselves believe in introducing new technologies to help them prevent, diagnose, treat, monitor, and care for patients.

Technology advancement has proven effective in providing access to information, facilitating remote care, improving efficiency by connecting the patients with physicians, cost-effective and time-saving solutions. Medical technologies encompass data centers, medical devices, software, drugs, IT services, public clouds, cybersecurity, communication services, surgical procedures, and Internet of things.

The medical technology market is growing fast in Asia, with different and bulky products available on almost all global markets. As a result, the global market for medical devices only is projected to grow from USD 455.34 billion in 2021 to USD 657.98 billion in 2028.

The key challenges humping the development of medical technology are biomedical complexity, standardization,
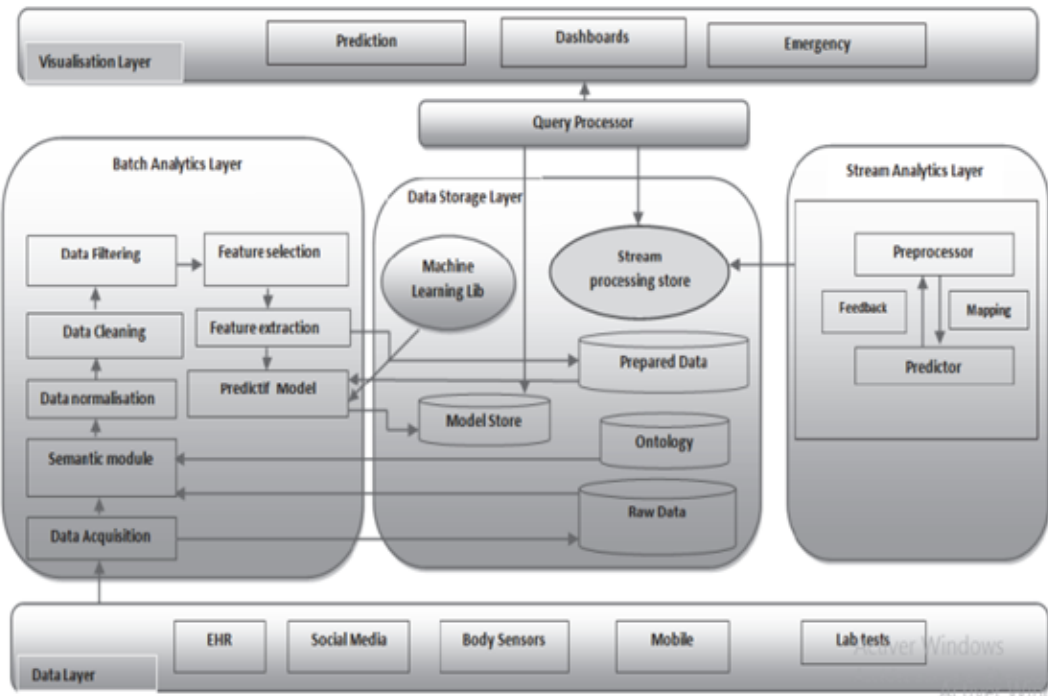
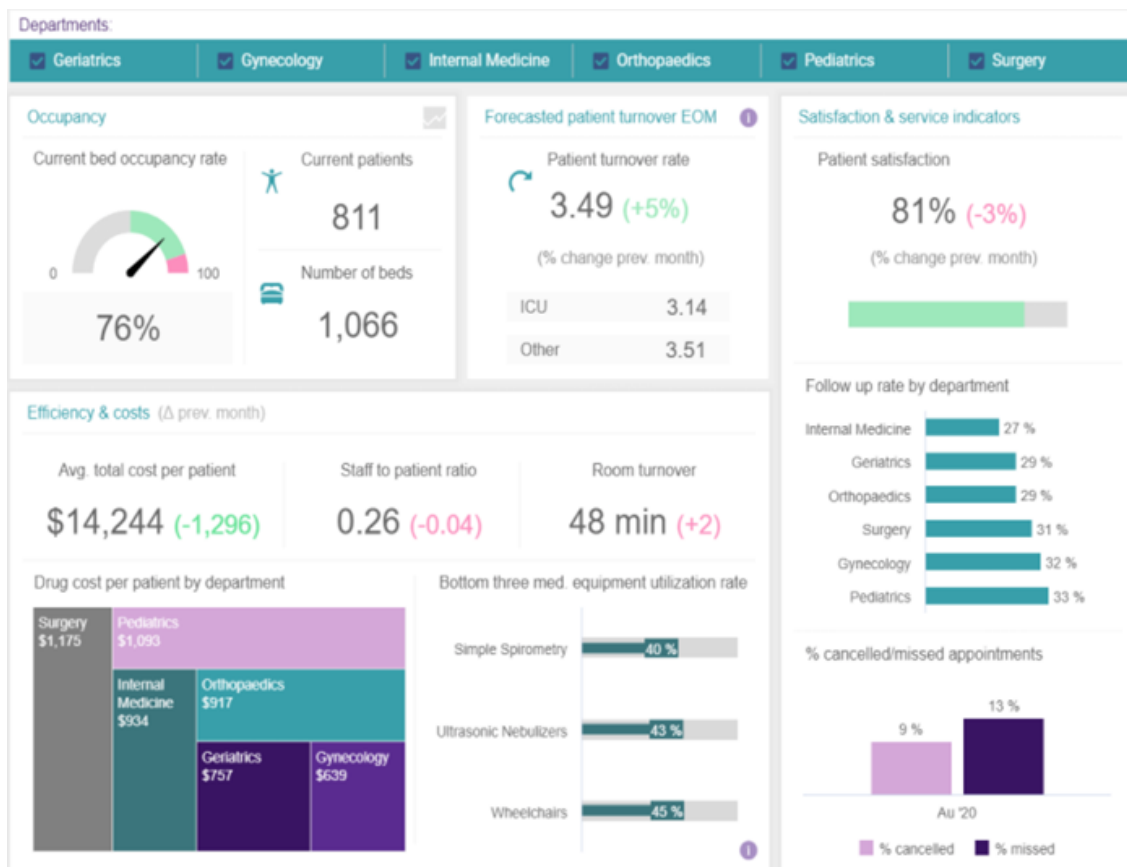**FIGURE 25.** Big Data architecture for health system.[148]

FIGURE 25. Big Data architecture for health system.[148]

cybersecurity and data privacy, higher starting costs, and regulatory and environmental consideration.

The revolution of healthcare technology applications in medical services requires knowledge and skills in assessment, planning, procurement, inventory management, installation, and maintenance. Therefore, healthcare providers need to be watchful about Healthcare Technology Assessment (HTA) to ensure evidence about safety, effectiveness, relevance, technology outcomes, and alternative technologies when running a particular technology. HTA is a multidisciplinary process that summarizes information about the medical, social, economic, and ethical issues related to using health technology systematically, transparent, unbiased, and robustly.

According to World Health Organization, only 70 countries worldwide have a National Agency or committee that provides HTA reports to the Ministry of Health, among which only 3 countries come from Africa (Benin, Mali and South Africa). Governments are therefore encouraged to adopt HTA programs because they provide information to support decisions about priorities in healthcare. Furthermore, HTA involves different parties, including patients' experience, caregivers, policymakers, physicians, HTA agencies, clinical engineering industry representatives, payers, pharma groups, and finance managers.

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