HISTORY AND FUTURE OF DIGITAL HEALTH

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1. WHAT IS DIGITAL HEALTH?

Digital health refers to the use of digital technologies for providing healthcare. In its earlier avatar, it was called eHealth (with the usage of IT and communication technologies), and then mHealth (with the usage of mobile technologies).

> *Now digital health, encompasses both eHealth and mHealth, and refers to provision of healthcare leveraging advanced technologies like big data and analytics, artificial intelligence, IoT, and genomics.*

The Stanford Center for Digital Health identifies five digital health technology categories:[1]

1. Artificial intelligence (AI), machine learning (ML), and algorithms (including deep learning, image processing, and advanced analytics)

2. Health IT, infrastructure, and data management (including Electronic Health Record systems)

3. Mobile and web applications (including online SaaS platforms, cloud-based software tools, and social media)

4. New clinical care models (including telemedicine, patient engagement, and patient– physician interaction)

5. Wearables, sensors, and other devices To the above, we will add another category – genomics and genetic technologies.

6. Genomics and genetic technologies (including technologies for genomic sequencing, editing and diagnostics like CRISPR, recombinant DNA, DNA array, functional genomics including mRNA analysis, computational biology and bioinformatics).

Stanford Center for Digital Health

1. **ARTIFICIAL INTELLIGENCE**
   Like computer vision for medical imaging: natural language processing for healthcare documentation, chatbots for patient interaction

2. **HEALTH IT & DATA MANAGEMENT**
   Like data registries, data streams that feed automated clinical decision support systems, network solutions and cloud services for remote access of patient data

3. **MOBILE & WEB APPS**
   Like telemedicine, asynchronous communication, health apps, remote data collection and transfer.

4. **NEW CLINICAL CARE MODELS**
   Like telesurgery, remote patient monitoring, and patient engagement though social media.

5. **WEARABLES & DEVICES**
   Like wristbased activity trackers, wearable ECG monitors, virtual reality headsets, novel biosensors.

Technologies enable digital health interventions at two ends of the complexity spectrum. At one end, they allow the public to discover basic healthcare information, such as ‘how many people in a region are registered into a health system’, and ‘supply of healthcare workers, health facilities and supplies’, and help address gaps in achieving Universal Health Coverage. At the other end, digital technologies make sophisticated health interventions possible – like AI technologies assisting in medical diagnosis, prognosis, and faster drug discovery, and 5G technology enabling real-time remote surgery.

In this new wave of technological revolution that humankind is experiencing, there is a blurring of lines between the physical, digital, and biological worlds. Before we explore this dazzling future of digital health, let us walk down history lane to understand its genesis.

2. HISTORY OF DIGITAL HEALTH

We will consider four different areas in medicine and healthcare for this historical exploration – 1) Computing and data analysis 2) Artificial Intelligence 3) Medical imaging, Robotics and Wearables 4) Telemedicine.

2.1. Genesis of computing and data-analysis in medicine and healthcare

114 YEARS AGO,
at Mayo Clinic, the practise of maintaining individual patient records began

On 19 July 1907, a patient was registered at the Mayo Clinic, US, thus launching the system, developed by Henry Plummer and Mabel Root, for maintaining individual patient-records on paper, a precursor to electronic medical records. Mayo Clinic even had special paper, that did not turn brittle or yellow, and special ink for this purpose. Their publication, Mayovox, said, “Clinic records are priceless, a note on a patient’s condition today may be the diagnostic key to solution of that same patient’s medical problem a quarter-century from now.”[2] More patient data began to be collected. The first medical questionnaire to come into general use was the Cornell Medical Index. Devised by K. Brodman, in the late 1940s, it consisted of a form containing 195 questions which was given to the patient immediately before the physician visit.

Data analysis techniques began to be increasingly employed for medical diagnosis, and provided for a more formal method in medical decision making. In 1947, Jacob Yerushalmy evaluated statistical hypothesis-testing methods for medical diagnosis of X-rays.[3] In 1958, M. Lipkin and J.D. Hardy showed how classification and correlation of data might assist in the differential diagnosis of haematological diseases.[4] In 1959, Robert Ledley and Lee Lusted published a paper in Science, explaining the importance of reasoning processes and mathematical methods like Boolean algebra and Bayes theorem in medical diagnosis, and discussed the potential role of electronic computers.[5]

FROM THE 1940S,
mathematical and statistical methods were increasingly used in data analysis for medical diagnosis

In 1960, James Shannon, Director of the National Institute of Health, US, created an advisory committee to explore the potential of computers in biomedicine. Subsequently, several American universities established work in this direction. The Data Processing Laboratory at the Brain Research Institute in UCLA Medical School became the first integrated electronic and computer laboratory established for the express purpose of developing automated technology for nervous system research.[6] In 1961, MIT's Lincoln Laboratory developed LINC (Laboratory Instrument Computer), the world's first minicomputer and a forerunner to the PC.[7] Twelve LINCs were placed initially in biomedical research laboratories across US under a unique NIH-sponsored evaluation program.

IN 1965

The first interactive patient-dialogue medical history system was created

One such laboratory was at the Department of Medicine in the University of Wisconsin, where, in 1965, Warner Slack and Philip Hicks developed the first on-line LINC computer-based medical history system, that engaged in an interactive dialogue with a patient.[8] The next year, they developed a LINC-based clinical laboratory system, to collect and interpret laboratory results from auto-analysers and laboratory technologists. This work, later in collaboration with Digital Equipment Corporation, became LABCOM, one of the first commercially available and widely deployed clinical laboratory programs.[9]

In 1965, Octo Barnett led a team at the Laboratory of Computer Science in Massachusetts General Hospital (MGH) which worked with Bolt Beranek and Newman (BBN) to develop a PDP-1 based remote-access, time-sharing system for admission discharge census, laboratory reporting, and medication ordering. In an interesting aside, the hospital and the technical vendor differed widely in how they perceived the collaboration – MGH called off the project because they found the electronic medical records system did not scale well in the real-world and was unavailable for hours at a time; for BBN, the technical demonstration was an outstanding success, which enabled them to win a bid to create ARPANET (the earlier avatar of the Internet).[10] This is a narrative which gets repeated even today, especially when doctors and computer scientists differ sharply over the utility of an AI system for medical diagnosis.

A CASE OF DIFFERING PERCEPTION OF VALUE

between a hospital and a technology solution provider

A couple of years later, the laboratory came up with Massachusetts General Hospital Utility Multi-Programming System, or MUMPS, a programming language that could support a large-scale hospital system. MUMPS, now commonly known as M or Cache, remains the basis of systems at many large hospitals and banking institutions even today.[11] In 1975, the laboratory used MUMPS to develop COSTAR (Computer Stored Ambulatory Record) for the Harvard Medical School, one of the earliest electronic health records (EHR) systems. In 1979, Judith Faulkner launched Epic Corporation (started as Human Services Computing), a world leader in EHR systems today.

DIGITISATION OF MEDICAL INFORMATION –FIRST MEDLARS AND LATER PUBMED

Another area where computing had a significant impact in healthcare was in the digitisation of medical information. In 1963, the National Library of Medicine developed Medical Literature Analysis and Retrieval System (MEDLARS), the first system to provide electronic bibliographic access and copies of medical literature. It has today evolved to become PubMed, a database containing 32 million citations and abstracts of biomedical and life-sciences literature.[12] In 1986, D. A. Lindberg, as Director of the National Library of Medicine, guided the development of the Unified Medical Language System which became a foundational component within medical informatics. Its purpose was to improve the ability of computer programs to understand the biomedical meaning in user inquiries to retrieve and integrate relevant information for them.[13]

Refer to Table 1: Genesis of computing and data-analysis in medicine and healthcare.

Year	Milestone
1907	Dr. Henry Plummer and Mabel Root of the Mayo Clinic developed a system of maintaining individual patient records on paper
1940s	The first medical questionnaire to come into general use was the Cornell Medical Index.
1947	J. Yerushalmy evaluated statistical hypothesis-testing methods for screening and radiology (X-rays)
1954	FA Nash at Western Hospital, England developed a logical scheme using slide-rule for matching symptoms to diagnoses.
1958	M. Lipkin and J.D. Hardy showed how classification and correlation of data might assist in the differential diagnosis of hematological diseases.
1959	Paper by Robert Ledley and Lee Lusted in Science explained the reasoning processes inherent in medical diagnosis, and discusses the role of electronic computers to aid in this process.
1959	At the first IBM Medical Symposium, Frederick J. Moore of IBM proposed a vast information retrieval system that would make health data available to public and private agencies.
1960	James Shannon, Director of the National Institute of Health created an Advisory Committee on Computers in Research, and to explore the potential of computers in biomedicine.
1961	Data Processing Laboratory of the Brain Research Institute at UCLA Medical School was established
1961	Kaiser Permanente established the Department of Medical methods Research to use computers in the practice of medicine.
1961	Twelve LINCs, developed at MIT, were placed initially in biomedical research laboratories across US under a unique NIH-sponsored evaluation program.
1962	Robert Ledley, Frank Ruddle and Herbert Lubbs worked on early developments in computerized medical imaging and pattern recognition. To do chromosome analysis using a FIDAC film scanner that connected to an IBM 7090 computer.
1963	The National Library of Medicine used digital computers to automate the Index Medicus, and developed Medical Literature Analysis and Retrieval System (MEDLARS), which later evolved into PubMed.

Year	Milestone
1965	In a pioneering effort at the University of Wisconsin, Warner Slack and Philip Hicks developed the first on-line LINC computer-based medical history system. The next year, they developed a LINC-based clinical laboratory system.
1965	Octo Barnett at the Laboratory of Computer Science in Massachusetts General Hospital, with the Cambridge-based company Bolt Beranek and Newman, demonstrated a time-sharing, remote-access health information system.
1967	A programming language was developed, the Massachusetts General Hospital Utility Multi-Programming System (MUMPS), that could support a large-scale hospital system. The initial implementation was on a PDP-7 with 8K memory and 3 Teletypes.
1967	Gorry GA developed a system for computer-aided diagnosis using the time-sharing computer at Project MAC, MIT, which ultimately led to the development of a system for management of acute renal failure.
1969	HL Bleich developed an interactive computer system at the Boston Beth Israel Hospital to evaluate clinical and laboratory information concerning patients with acid-base disorders.
1971	Allen Ginsberg at the Rand Corporation developed a decision analysis system for clinical patient management with an application to the pleural-effusion syndrome.
1972	ARAMIS (The American Rheumatism Association Medical Information System), developed by James Fries, provided time-oriented patient records and a computer databank analysis for prognosis in an outpatient rheumatology clinic.
1972	de Dombal of the University of Leeds, England developed computer-based decision aids using Bayesian probability theory for investigation of abdominal diseases

Table 1: Genesis of computing and data-analysis in medicine and healthcare

2.2. Genesis of artificial intelligence (AI) in medicine and healthcare

We saw how, from the 1950s, various data analysis and statistical techniques (mathematical models, Bayesian analysis, pattern recognition, etc.) began to be increasingly deployed for medical diagnosis. The next important development, in 1965, was the Heuristic DENDRAL project at Stanford University, by AI pioneer, Edward Feigenbaum, and Nobel Prize winner, Joshua Lederberg. The rule-based and hypothesis-list approaches used in the system helped identify unknown organic molecules by analysing their mass spectrometry data.

The 1970s heralded the application of AI in medicine and healthcare. In 1971, the US National Institute of Health (NIH) established a pilot Research Resource on Computers in Biomedicine at Rutgers University, for supporting biomedical research with computational methods, including AI. In 1973, the NIH created the Stanford University Medical Experimental – Artificial Intelligence in Medicine (SUMEX-AIM) laboratory. The idea was to leverage the computing capabilities of the then newly introduced time-sharing computer, PDP-10, and support the AIM research of various groups at Stanford, Rutgers University, MIT, and the University of Pittsburgh.

Four different AI systems – INTERNIST 1, MYCIN, PIP, and CASNET – emerged in the 1970s.[14]

1. INTERNIST 1

In 1972, Jack Myers, chairman of department of medicine at University of Pittsburgh, and Harry Pople, a computer scientist with interest in AI, collaborated to develop Internist-1 for differential diagnosis in internal medicine. The system contained a knowledge base of causal and taxonomic relationships between clinical findings and diagnostic hypotheses, and used a powerful ranking algorithm to reach diagnoses.[15]

2. MYCIN

In 1976, E.H. Shortliffe, at the Stanford Medical School, developed the MYCIN rule-based expert system for infectious disease therapy assistance. In a comparative test, case histories of ten patients suffering from meningitis were submitted to MYCIN and to eight human physicians, for their diagnosis and recommendations. An independent assessment found that MYCIN scored higher on both accuracy of diagnosis and effectiveness of treatment.[16]

3. PIP

In 1976, Steven Pauker and Anthony Gorry at MIT and Tufts New England Medical Center, developed the Present Illness Program (PIP) system, an early diagnostic tool in the evaluation of patients with oedema. PIP had four major components: patient data, the knowledge repository of disease (representing a long-term memory), the intersection of patient data and the knowledge repository (representing a short-term memory), and a supervisor program to filter knowledge and act on patient input.[17]

4. CASNET

In 1978, Saul Amarel and Casimir Kulikowski of Rutgers University developed CASNET, Causal Associational NETwork model for consultation in glaucoma. It brought together ideas from two fields of computer science: statistical pattern recognition (inference networks and probabilistic scoring of hypotheses) and Artificial Intelligence (conceptual structure to represent disease processes, a model of disease separated from decision-making strategies).[18]

These went on to inspire the next generation of AIM applications in the US. A series of systems were developed that looked at causal reasoning / understanding of patient's illness in medical diagnosis, and providing explanation / justification for expert systems - Digitalis Therapy Advisor (by Gorry et al) in 1978, ABEL system (Ramesh Patil et al) in 1979, and XPLAIN system (by W. Swartout) in 1982. These new systems addressed some of the limitations of the first generation of AIM systems – no knowledge of the underlying causal mechanisms for the diseases, and inability to adequately deal with illnesses resulting from multiple diseases.

XPLAIN IN 1982

- one of the earliest examples of 'explainable AI' systems

The ABEL (Acid-Base and Electrolyte) system understood a patient's illness using a collection of data-structures called the patient-specific models which also contained causal interconnections among the data.[19] The XPLAIN system became an early example of an 'explainable expert system' or 'explainable AI' – one that explicitly distinguished different forms of domain knowledge, and offered enhanced capabilities in explaining and justifying the system's behaviour / conclusions.[20]

In 1984, the Laboratory of Computer Science at Massachusetts General Hospital began development on DXplain, a decision support tool that could help physicians make informed clinical decisions and diagnoses based on analysis of its database of around 2000 diseases.[21] In the Indian context, one of the earliest examples of AI in healthcare came in 1986, in the form of a project by H.N. Mahabala and team at IIT Madras as part of India's Knowledge-Based Computing Systems initiative – Eklavya was a knowledge-based program designed to support a community health worker in dealing with symptoms of illness in toddlers.[22]

EKALAVYA IN 1986

– the earliest example of AIM application in India

In 2020, Google DeepMind used AI to solve the ‘protein folding problem’, a grand challenge that existed for over fifty.[23] Their AlphaFold database of protein structures is expected to provide opportunities for new drug discovery and research in areas like structural biology and structural bioinformatics.

Refer to Table 2: Genesis of artificial intelligence (AI) in medicine and healthcare.

Genesis of artificial intelligence (AI) and robotics in medicine and healthcare

Year	Milestone
1972	INTERNIST-1 system for differential diagnosis in internal medicine was developed at University of Pittsburgh. Using LISP / Interlisp and on the PROPHET PDP-10 computer.
1975	The first seminar on AI in medicine, the Knowledge-based Systems in Biomedicine Workshop was held at Rutgers University.
1976	E.H. Shortliffe developed the MYCIN rule-based system for infectious disease therapy assistance at Stanford.
1976	PIP (Present Illness Program) for diagnosis-driven acquisition of clinical data was developed at MIT and Tufts.
1978	CASNET, Causal Associational NETwork model for consultation in glaucoma was developed at Rutgers University.
1979	The ABEL system, developed at MIT, allowed for causal representation of patient illness for electrolyte and acid-base diagnosis.
1982	XPLAIN, developed at USC, was used to generate a digitalis drug dosage advisor.
1983	William Clancey developed Guidon, an intelligent computer aided instruction system for teaching medical diagnosis.
1985	The US National Library of Medicine developed the Unified Medical Language System, which became a foundational component within medical informatics.
1986	DXplain, a decision support tool for clinical decisions and diagnoses, was released with a database of around 2000 diseases.
1986	Ekalavya, developed at IIT Madras, was a decision support system for a community health worker in dealing with symptoms of illness in toddlers.

Table 2: Genesis of artificial intelligence (AI) in medicine and healthcare

2.3. A brief history of medical imaging, robotics and wearables

Medical devices have been around for a very long time. One of the earliest instances was that of Neolithic dentists, from the stone-age 9000 years back, using dental drills.[24] We will explore a more modern history of medical devices, in three specific areas – medical imaging, robotics and wearables.

Medical imaging – Wilhelm Conrad Rontgen took the first X-Ray in 1895. In 1971, Godfrey Hounsfield and Allan Cormack processed the first computed tomography (CT / CAT) scan image. In the 1970s, scientists like Paul C. Lauterbur and Peter Mansfield helped develop Magnetic Resonance Imaging (MRI). Medical visualization became important, to extract meaningful objects from volumes of data. William E. Lorensen and Harvey E. Cline worked at General Electric on a way to efficiently visualize data from CT and MRI devices, and developed, in 1987, the Marching Cubes algorithm.

MARCHING CUBES, ML, DEEP LEARNING

–Algorithms in medical imaging

It was in the early 1990s that AI was used in medical imaging – computer-vision assisted expert systems were introduced for identifying image of the heart and correlating to coronary disease. Rule-based expert systems followed. But AI was not scalable then. From 2004 onwards, newer techniques of combining visualization with computer vision were developed to handle multi-modal data, and brought AI back into the fold. [25] As computational capabilities improved, ML algorithms helped with better assessment of the boundary of images and identifying features. Deep learning has profoundly changed the medical imaging space – features in a medical image are now learnt by the neural network.

Robotics – In 1988, the first instance of a robot, Westinghouse Electric's Unimation Puma 200, was seen in a surgery theatre for needle placement in a CT-guided brain biopsy.[26] In the 1980s and 1990s, research teams at Ames Research Center, NASA and Stanford undertook the development of telepresence surgery using virtual reality and surgical robots.

Computer Motion began in 1989 as a robotics research lab with funding from NASA. In 1994, they developed the first robot that was approved by the US Food and Drug Administration for clinical use in abdominal surgery, the Automated Endoscopic System for Optimal Positioning (AESOP).[27] Intuitive's DaVinci robotic surgical system, which is one of the most ubiquitous and recognized systems in the world today, was made available in Europe in 1999, and got an US FDA approval for a medical device that incorporated 'weak AI' in 2000.

1988

– the first robot used in medical surgery

2000

– the first FDA approved robot with 'weak AI'

The next year, 2001, witnessed the landmark 'Lindbergh operation', which was the first complete tele-surgical operation carried out by Jacques Marescaux and team located in New York on a human patient in Strasbourg, France (over a distance of several thousand miles), using a Socrates robot along with Zeus robotic system.[28] Although the demonstration was successful, remote surgery did not become commonplace because of latency issues in the communications network. It took 18 years and new technologies like 5G to address that challenge. In 2019, China successfully completed the world's first remote surgery using 5G mobile network technology – a remote hepatic lobectomy was performed on pigs, while the operation signal was transmitted in real time from a site 50 KM away.[29] And a few months later in China, a surgeon remotely conducted a brain surgery on a Parkinson's patient 1,800 miles away using machines on a 5G network.[30]

Wearables – They are miniaturized medical devices typically worn on the body, to monitor health parameters of the person wearing it. Technologies like IoT, sensors, wireless networking have transformed the world of wearables. Remarkably, the first 'wearable' was designed in 1472 – you read that right! Researchers have found sketches of the first pedometer among Leonardo da Vinci's works.[31] The twentieth century saw the advent of a number of wearables – the first wearable hearing aid (1938), implantable pacemaker (1958), and the first digital home glucose meters (1987). The twenty-first century saw the big tech companies like Apple and Google foray into health-wearables in a big way.

1472

– Leonardo da Vinci designed the first wearable, a pedometer

Refer to Table 3: A brief history of medical imaging, robotics, and wearables in medicine and healthcare.

A brief history of medical imaging, robotics, and wearables in medicine and healthcare

Year	Milestone – Medical Imaging & Robotics
1972	Godfrey Hounsfield and Allan Cormack processed the first CT image.
1973	Robert Ledley developed the first whole-body CT scanner, called the ACTA Scanner, which became operational at the Georgetown University Hospital.
1975	DeltaScan, the first clinical CT scanner developed that used digital algorithms to acquire and convert electronic signals to visual representations.
1987	The Marching Cubes algorithm was developed to visualize data from CT and MRI devices.
1988	A Unimation Puma 200 (Westinghouse Electric, Pittsburgh, PA) was used for needle placement in a CT-guided brain biopsy.

Year	Milestone – Medical Imaging & Robotics
1991	University of Lausanne's Minerva System was the first one of its kind to not rely on pre-operative imaging, and instead use real time image-guidance in neurosurgery.
1994	Automated Endoscopic System for Optimal Positioning (AESOP) became the first robot to be approved by the Food and Drug Administration (FDA).
1995	NASA's Robot-Assisted Microsurgery System was the first neuro-surgery robotic system that allowed for the use of MRI instead of CT scans.
2000	Intuitive's DaVinci robotic surgical system incorporated 'weak AI' in an FDA approved medical device.
2001	Computer Motion, Inc built the SOCRATES Robotic Telecollaboration System, that facilitated remote surgical telecollaboration.
2019	Suzhou Kangduo Robot Co's MFC 2018, a four-hand laparoscopic surgical robot, was used in the world's first 5G-enabled remote surgery. Year Milestone – Wearables

Year	Milestone – Wearables
1938	Chicago electronics manufacturer, Aurex Corp, developed the first wearable hearing aid.
1958	The first implantable pacemaker, a Siemens-Elema device was installed.
1962	The first Holter monitor, ambulatory EKG machine, was sold.
1983	Finland's Polar Electro introduced the first wireless consumer heart rate monitor.
1983	The MiniMed 502, a wearable insulin pump was launched. By 2006, the next versions included wireless controls and real-time biosensor feedback features.
1987	Medisense shipped the first digital home glucose meters.
2009	Fitbit Tracker is launched. Google acquired Fitbit in 2021.
2018	Apple gets FDA approval for its electrical heart rate sensor embedded within the Apple Watch 4.

Table 3: A brief history of medical imaging, robotics, and wearables in medicine and healthcare

2.4. A brief history of telemedicine – worldwide and India

In 2020-21, telemedicine became popular due to the constraints imposed by the pandemic. Its origins, though, could be traced back to the American Civil War, 150 years ago, when the medical officer used telegraph to request medical supplies. In 1879, The Lancet described a case of usage of telephone in remote diagnosis - the physician heard a child cough over a telephone and diagnosed it was not a case of croup. 1906 was the first time the phrase 'tele' was used to describe a medical service, when Einthoven recorded electrocardiograms remotely and called it telecardiogram. In 1920, Bergen's Haukeland Hospital in Norway established a radio service to provide clinical support for ships at sea. Other Western European countries soon followed suit. In 1925, Hugo Gernsback predicted in an article in 'Science and Invention' magazine that a device, 'teledactyl', would be available in 1975 - it would allow doctors to diagnose a patient by radio, see their patients through a viewscreen, and touch them from miles away with robot arms.

TELEMEDICINE GOES BACK 150 YEARS

– telegraph and telephones were used for medical supplies and diagnosis

In 1960, a closed-circuit television link was set-up for psychiatric consultations in Nebraska, US, and it was the first instance of usage of video in teleconsultation. In the 1960s, NASA, the US space agency, was working on technologies to send biometric data, of animals on the Mercury and Gemini flights, to scientists on Earth via a telemetric link. In 1971, this work translated into establishment of a large telemedicine service program in a Native American reservation in South Arizona, which eventually translated into widespread adoption of telemedicine, especially during emergency scenarios.

In India, telemedicine was born in 2000-01, when the Indian Space Research Organization partnered with Apollo Telemedicine Enterprises to launch Satcom-based telemedicine services in India by connecting Apollo Hospital Chennai with a healthcare facility in the village of Aragonda in Andhra Pradesh. A year later, India's first telemedicine network, between three institutions AIIMS-New Delhi, PGI-Chandigarh & SGPGI-Lucknow, was created.

2000

- Telemedicine began in India in Aragonda village, Andhra Pradesh

Two decades later, in 2020, there was a flurry of actions that provided a big boost to telemedicine – India's Telemedicine Practice Guidelines were released; the Government of India launched the eSanjeevani telemedicine platform during the pandemic; and also announced the National Digital Health Mission, now called Ayushman Bharat Digital Mission, that hopes to transform digital healthcare in India.

Refer to Table 4: Brief History of Telemedicine – Worldwide and India. [32, 33, 34, 35, 36,37, 38, 39, 40, 41, 42]

A Brief History of Telemedicine - Worldwide

Year	Milestone
1863	Major Albert Myer, a surgeon and medical officer in the Union Army during the American Civil War, used the telegraph to request medical supplies and coordinate the transport of patients
1879	An article in the Lancet described a case of use of telephone in remote diagnosis - the physician heard a child cough over a telephone and diagnosed it was not a case of croup.
1906	W. Einthoven recorded electrocardiograms on a galvanometer in his laboratory, while his patient was in a hospital some distance away, and the impulses were transmitted through telephone wire. He called this technique "telecardiogram".
1920	Bergen's Haukeland Hospital in Norway established a radio service to provide clinical support for ships at sea. Other Western European countries soon followed suit.
1950	Gershon-Cohen, a radiologist, and Autin Cooley, a telecommunications inventor, transmitted X-ray images over wire or radio circuits over a distance of twenty-eight miles between the Chester County Hospital, West Chester, and Philadelphia, Penna. They called it 'telognosis' or 'teleo roentgen diagnosis'.
1957	Albert Jutras, a radiologist in Montreal demonstrated the feasibility of transmitting radiographic images via coaxial cable between the Hotel-Dieu and the Jean-Talon Hospitals, about 5 miles apart.
1959-60	A closed-circuit television link was established between the Nebraska Psychiatric Institute and Norfolk State Hospital for psychiatric consultations.
1964	NASA, the U.S. space agency, introduced the Integrated Medical and Behavioral Laboratories and Measurement Systems program - based on the systems on Mercury and Gemini flights which sent animal's biometric data to scientists on Earth via a telemetric link.
1968	The first prototype telemedicine program was established in Boston, linking the Medical Station at Logan International Airport with Massachusetts General Hospital.
1971	NASA launched the Space Technology Applied to Rural Papago Advanced Health Care program, to provide telemedicine services to the remote location of the Tohono O'odham Native American reservation in South Arizona.
1997	NASA established the Medical Informatics and Technology Applications Consortium, which brought telemedicine to remote locations on Earth, like the top of Mt. Everest

A Brief History of Telemedicine - India

Year	Milestone
2000-01	The Indian Space Research Organization (ISRO) partnered with Apollo Telemedicine Enterprises to launch Satcom-based telemedicine services in India by connecting Apollo Hospital Chennai with a healthcare facility in the village of Aragonda in Andhra Pradesh.
2001	India's first telemedicine network between three institutions AIIMS-New Delhi, PGI-Chandigarh & SGPGI-Lucknow is created, after a pilot study in 1999. Telemedicine Society of India formed.
2004	Integrated Disease Surveillance Project (IDSP) was launched with World Bank assistance by Ministry of Health & Family Welfare, connecting 776 sites in States/District HQs and premier institutes.
2005	MoHFW constituted Indian Task Force for Telemedicine
2009-10	Government initiatives like National Rural Telemedicine Network, National Medical College Network, Onco-NET conceived
2011	National Resource Centre for Telemedicine established at SGPGI, Lucknow
2013	National Resource Centre for EHR standards established at CDAC Pune
2016-18	Revised Electronics Health Record (EHR) Standards (initially in 2013) and Health Metadata & Data Standards (MDDS) notified .
2017-19	National Health Policy articulated a vision to digitize healthcare in India (2017) NITI Aayog released a report on National Health Stack (2018) National Digital Health Blueprint report submitted to the Ministry of Health (2019)
2018	CORS (CollabDDS Online Radiology Services) is launched for 79 Primary Healthcare Centres for Tele-Radiology consultation
2019	National Medical College Network (NMCN) is live at 50 Govt. Medical Colleges interconnected on the National Knowledge Network for Doctors/Students for Tele-Education, Remote learning.
2020	National Digital Health Mission launched - pilot underway in 6 Union Territories, NDHM Sandbox environment created. Telemedicine Practice Guidelines 2020 released. eSanjeevani Telemedicine Platform modified for providing Online consultation to patients directly as part of MoHWF's National Teleconsultation Service.

Table 4: Brief History of Telemedicine – Worldwide and India

3. FUTURE OF DIGITAL HEALTH

The journey to discover the genesis of digital health has indeed been fascinating – telemedicine started 150+ years back, data analysis in healthcare began over 100 years ago, and AI in medicine over 50 years back. A number of perspectives spring to mind as we internalise this history and envisage the future of digital health.

First, the pace of change of emerging technologies is dramatic. Information technology and biotechnology are entering the second half of the technological chessboard – computing power is growing fast pushing Moore's Law to its breaking point, and we have seen an explosion of AI-enabled applications in healthcare and other walks of our lives; similarly, Flatley's Law governing DNA sequencing is being stretched to its limit, resulting in applications like personalised medicine and targeted cures. There is no doubt that medicine and healthcare will be profoundly impacted.

Second, innovations occur at the intersection of domains – developments in other seemingly unrelated fields (e.g., chemistry, metallurgy, electronics, quantum physics etc.) are often major contributors to healthcare advances. Therefore, in predicting the future of healthcare, one will have to keep watch of the medical, non-healthcare, and inter-disciplinary trends.

Third, innovations in healthcare have much slower ramp-up curves than in other industries like manufacturing and technology. New techniques and technologies need to be understood by the doctors, tried carefully and then adopted. Typically, it takes 15–20 years for a new innovation to become mainstream in modern medicine. However, the COVID-19 pandemic has forced a change in behaviour, of patients, healthcare professionals and policy makers – there is a greater acceptance of digital technologies in healthcare now; perhaps even an increased willingness to accelerate medical solutions into the hands of the public (public benefit Vs risk balance). How will these trends hold up in the future?

The future of digital healthcare will be determined, ultimately, in a battle between the faster arc of digital transformation and the slower curve of societal transformation.

The future of digital healthcare will be determined, ultimately, in a battle between the faster arc of digital transformation and the slower curve of societal transformation. Let us explore this future, keeping the doctor and the patient at the centre of our analysis.

3.1. Future of doctor-patient interaction

The doctor-patient interaction is at the core of any healthcare practise. At the most basic level, the process is as follows – 1) the doctor collects information from and about the patient, 2) analyses the information (from patients' history and examination) to form a medical diagnosis and identify the underlying disease, and 3) recommends a course of action. It will be useful to view technology as a tool that has evolved over the years, and which has enabled every stage of this process, improving its effectiveness and efficiency.

Let us begin with a doctor speaking with and examining a patient. Typically, the patient describes her symptoms from memory. And in some situations, doctors have to reconstruct events from sketchy information (e.g., the exact nature of body movements during an epileptic seizure). The typical tools that a doctor uses today for examination are at least a century old – the stethoscope (invented 1816), sphygmomanometer (1881), knee hammer (1888), ophthalmoscope (1857) and thermometer (1714) are all antiquated!

The future of digital-health data collection will be different. Patients will record events like seizures on video, and AI systems will analyse the images, and doctors will get a list of possible diagnoses to choose from. Similarly, just the gait (a persons' manner of walking) of a patient can be diagnostic of many disorders (e.g., small shuffling steps may meanParkinson's disease), and video systems operating in doctors' clinics will help diagnose these disorders easily. Thus, the smartphone camera empowered with backend AI algorithms will become an image recording and recognition system that will help doctor evaluate patient body structures, facial expressions, skin lesions like suspected melanomas and many more. For instance, researchers in India have developed an AI-powered, smartphone-based anthropometry tool that empower frontline health workers to screen low-birth-weight babies.[43]

The smartphone camera empowered with backend AI algorithms will become an image recording and recognition, and sound monitoring system

Voice and manner of speaking are other obvious data points that patients produce (e.g., patients with depression have characteristic speech patterns), and advances in voice recognition systems will empower doctors to decode the underlying problems without having to become linguistic experts. A smartphone app will become a sound monitoring system that will record patients' heart, lung, bowel, and joint sounds, compare them with large datasets of millions of similar sounds, and give doctors a real-time interpretation of these sounds. For instance, researchers have developed solutions that utilise mobile-phone-recorded cough and machine learning models to accurately detect coronavirus even in people with no symptoms.[44]

A biomarker revolution is upon us and it will define how information will be collected from our bodies – besides the classical blood tests and imaging biomarkers (MRI etc.), new types of molecular biomarkers (e.g., for drug exposures, certain genomic or proteomic signatures etc.) are being discovered.

In recent times, Clustered Regularly Interspaced Short Palindromic Repeats, CRISPR technology has been applied to medical diagnostics – one typically needs a lab and high-end equipment to amplify a nucleic-acid signal in regular diagnostics; whereas with CRISPR, analysis can be done at room temperatures, and at home.

A biomarker revolution will lead to a new understanding of disease categories

As we gain additional information from molecular, imaging, therapeutic, and temporal patterns of many diseases, we realize that the traditional disease-categories need to be revised. So, lung cancer is not one disease, but of many different types. Same for diabetes. Same for stroke. As clinical data of millions of patients gets compiled into unified databases which can deploy novel AI algorithms to detect patterns that are undetectable by humans, our understanding of diseases will become more detailed and real-time. Patients will be able to get predicted trajectories of their diseases (e.g., when a diabetic might expect to get a retinopathy) and take necessary steps to change those trajectories.

Treatment of disease involves either a surgical procedure or medications. Most surgeries are done for one of four reasons: fix-it (e.g., bone fracture), remove-it (e.g., brain cancer), replace-it (e.g., failed kidneys) or augment-it (e.g., larger breasts). Over the next decade, the first two will continue to be important, but the real revolution will happen in the last two as replacement and augmentation become mainstream.

Newer forms of medical therapies will emerge – implantables, CRISPR-based

Newer implantable devices will augment various human capabilities including vision, hearing, memory, walking, eating, drinking and many others. Researchers are working on brain-machine interfaces to connect humans and computers[45], and systems which bypass the eyes to bring artificial vision directly to the brain.[46] Expansion of human capabilities through surgical procedures will become common.

Medical treatments will become more targeted and more expensive as molecular and genomic therapies become more effective and common. CRISPR, a revolutionary new technology for gene-editing, is being leveraged for new therapies for diseases – such as sickle-cell disease[47], and other diseases including cancer.[48]

It is clear that emerging technologies will profoundly impact the future of digital health. At the same time, they will also introduce certain challenges, of technological and ethical considerations, which the society needs to navigate carefully.

3.2. Responsible use of emerging technologies in medicine and healthcare

William Schwartz, a physician at the Tufts University School of Medicine and an early researcher into AI applications to medicine, noted in a 1970 article,

> *"It seems probable that in the not too distant future the physician and the computer will engage in frequent dialogue, the computer continuously taking note of history, physical findings, laboratory data, and the like, alerting the physician to the most probable diagnoses and suggesting the appropriate, safest course of action. One may hope that the computer, well equipped to store large volumes of information and ingeniously programmed to assist in decision making, will help free the physician to concentrate on the tasks that are uniquely human such as the application of bedside skills, the management of the emotional aspects of diseases, and the exercise of good judgment in the non-quantifiable areas of clinical care."*[49]

Has technology lived up to this promise? Have emerging technologies been so accurate and reliable that doctors could simply accept technology-based solutions in full faith? The reality is that we have seen mixed results – there are certain processes that are possible only because of technology (e.g., medical imaging, large scale medical data computation etc.), and there are some functions where the physician's intuitive judgement is much better than any AI-based diagnosis.

In 2012-13, IBM Watson, an AI system, was deployed at hospitals like the Memorial Sloan Kettering Cancer Centre and the MD Anderson Cancer Center in Houston, for developing oncological healthcare solutions. Watson for Oncology was supposed to learn from the vast medical literature on cancer and the health records of cancer patients. But these two experiments were stopped after only a few years. Like the 1965 case between MGH (hospital) and BBN (technology vendor), these projects suffered from an expectation-mismatch, which an IEEE Spectrum report described as, "a fundamental mismatch between the promise of machine learning and the reality of medical care—between 'real AI' and the requirements of a functional product for today's doctors."[50]

Mismatch between the promise of AI/ML and the reality of medical care

In the last year, hundreds of AI-tools have been rushed into healthcare practice, purportedly offering prediction models for diagnosis and prognosis of COVID-19. However, they have flattered to deceive – two major research studies evaluated 232 and 415 such published AI tools and algorithms, and found just two and none, respectively, fit for clinical use![51] These tools suffered from poor quality of data, often from unknown sources, and showed a high risk of bias.[52]

We are not suggesting that AI tools are completely unsuitable for use in medicine and healthcare. If these AI tools are designed well, they can produce reliable and accurate results, and be beneficial to doctors in medical diagnosis and prognosis.

The World Health Organisation has recently proposed six guiding principles for AI-in-healthcare design and use –
1) Protecting human autonomy
2) Promoting human well-being and safety and the public interest
3) Ensuring transparency, explainability and intelligibility
4) Fostering responsibility and accountability
5) Ensuring inclusiveness and equity
6) Promoting AI that is responsive and sustainable.[53]

Not just with AI, similar concerns have been raised with other emerging technologies in medicine as well. With wearables, concerns of privacy and security are particularly important. Similar concerns of privacy have been raised when pandemic-surveillance technologies, like contact tracing mobile-apps, were deployed in recent years.

Guiding principles for emerging technologies (like AI, gene-editing) in medicine and healthcare have been

Take the case of CRISPR gene-editing technology – researchers and bioethicists have raised a number of concerns including
1) safety – due to off-target effects of gene edits
2) use for non-therapeutic and cosmetic purposes
3) lack of informed consent from embryos and future generations that are affected by the gene edits
4) equity – it may be available only to the wealthy
5) moral / religious considerations – gene editing in human embryos.[54]

As genomic technologies evolve, they will have to be guided by certain globally accepted ethical standards and principles.

In this section, we glimpsed at the future of digital health through the lens of a doctor-patient interaction. In the next section, let us look at what will happen when these interactions happen at a population scale.

3.3. Public health and epidemiology at population-scale

I) Key digital health initiatives in the world

The COVID-19 pandemic has catalysed the adoption of digital health worldwide. Phrases like 'public health' and 'epidemiology' have entered popular jargon. Governments are conducting epidemiological surveillance, case identification and contact tracing, and predicting the waves of infection in specific geographies. They are making use of telecommunication technologies, advanced data analytics and machine learning, and data visualization techniques for these purposes. Refer to Table 5 for a summary of digital technologies in the public-health response to COVID-19. [55]

Public-health need	Digital tool or technology	Example of use
Digital epidemiological surveillance	Machine learning	Web-based epidemic intelligence tools and online syndromic surveillance
	Survey apps and websites	Symptom reporting
	Data extraction and visualization	Data dashboard
Rapid case identification	Connected diagnostic device	Point-of-care diagnosis
	Sensors including wearables	Febrile symptoms checking
	Machine learning	Medical image analysis
Interruption of community transmission	Smartphone app, low-power Bluetooth technology	Digital contact tracing
	Mobile-phone-location data	Mobility-pattern analysis
	Social-media platforms	Targeted communication
Public communication	Online search engine	Prioritized information
	Chat-bot	Personalized information
Clinical care	Tele-conferencing	Telemedicine, referral

Table 5: Digital technologies in the public-health response to COVID-19 (Source: Nature Medicine)

II) Key digital health initiatives in India

In India too, several initiatives have come up for developing epidemiological model for COVID-19 to provide inputs to Indian policy makers. A number of other initiatives have been undertaken in India that focus on creating, monitoring, and analysing healthcare data.

What has been heartening is that these initiatives have been undertaken not just by the Government, but also by the private sector and the civil society, often coming together as volunteering networks. Such data collection and monitoring initiatives will only grow as the need for robust public health systems grows.

Refer To Table 6 for a summary of some of the key digital health initiatives undertaken in the last few years, by the Government, private sector and the civil society.

Digital Health Initiatives

- Department of Science and Technology initiated COVID 19 Indian National Supermodel coordinated by JNCASR and IISc
- SUTRA model by professors from IIT Kanpur and IIT Hyderabad
- Indian Scientists' Response to COVID 19 group's INDSCI SIM model
- A total of 17 National COVID19 bio repositories identified by ICMR and other Government agencies will be established
- Indian SARS CoV 2 Genomics Consortium (INSACOG) has been set up for genomic surveillance of SARS CoV 2 in India
- The Department of Biotechnology started the "Genome India Project" with the aim to collect 10,000 genetic samples from citizens across India, and to build a reference genome an exhaustive catalogue of genetic variations for the Indian population
- The Government of India developed AarogyaSetu, a contact tracing app to track COVID 19 patients, and CoWIN, a digital platform to support the pandemic vaccination drive
- National Digital Health Mission (We will explore this in greater detail below.)

Digital Health Initiatives Private sector & Civil Society

- Several private hospitals have embraced digitalisation and adopted telemedicine. For instance, the Apollo 24/7 initiative integrated 2,500 of hospital beds and another 2,000 hotel beds, plus home care, to create a complete COVID 19 solution, making it the largest effort outside government in India

- The Tata Trusts are using the 'digital nerve centre' (DiNC) technology platform to connect the top Cancer Hospitals in the National Cancer Grid. This allows data sharing across these centres, and enables delivery of comprehensive cancer care service to patients

- Swasth Digital Health Foundation is a not for profit consortium of 150+ players in the healthcare ecosystem hospitals, health tech firms, pharmacies, and investment funds and aims to help India provide quality healthcare using digital technologies to build an effective tele medicine platform for a large segment of population that doesn't have access to affordable healthcare; build public digital health infrastructure foundational blocks of open, interoperable health stack

- Project StepOne is a collation of technologists and 7000+ volunteer doctors helping governments manage the COVID 19 crisis through free telemedicine. Their solution works without smart phone or internet or the need for the caller to be literate as they can speak in their own language with the IVR & doctors

- Other non profit volunteering organizations working on digital health include iSPIRT (open house discussions and pilots on national health stack), and CoronaSafe Network (open source software for pandemic management war rooms).

Table 6: Key digital health initiatives – Government, private sector, and the civil society

III) Ayushman Bharat Digital Mission (ABDM) in India

The pandemic forcefully brought out globally the need for national IT infrastructure – to generate accurate and real-time estimates of disease incidence which will help in efficient allocation of scarce medical resources, and to track, trace, and quarantine affected individuals during times of public health emergencies.[56] In India, in August 2020, the Prime Minister launched the Ayushman Bharat Digital Mission that aims to create an 'open digital health ecosystem'.

Building blocks of the Digital Health Stack

The Digital Health Stack will be a shared digital infrastructure that will be leveraged by both public and private enterprises to build and provide innovative healthcare solutions. The key building blocks of this digital stack include standardized health registries of doctors and healthcare facilities like hospitals and diagnostic centres , a unique patient identity (Health ID), and federated health records (PHR and eMR).

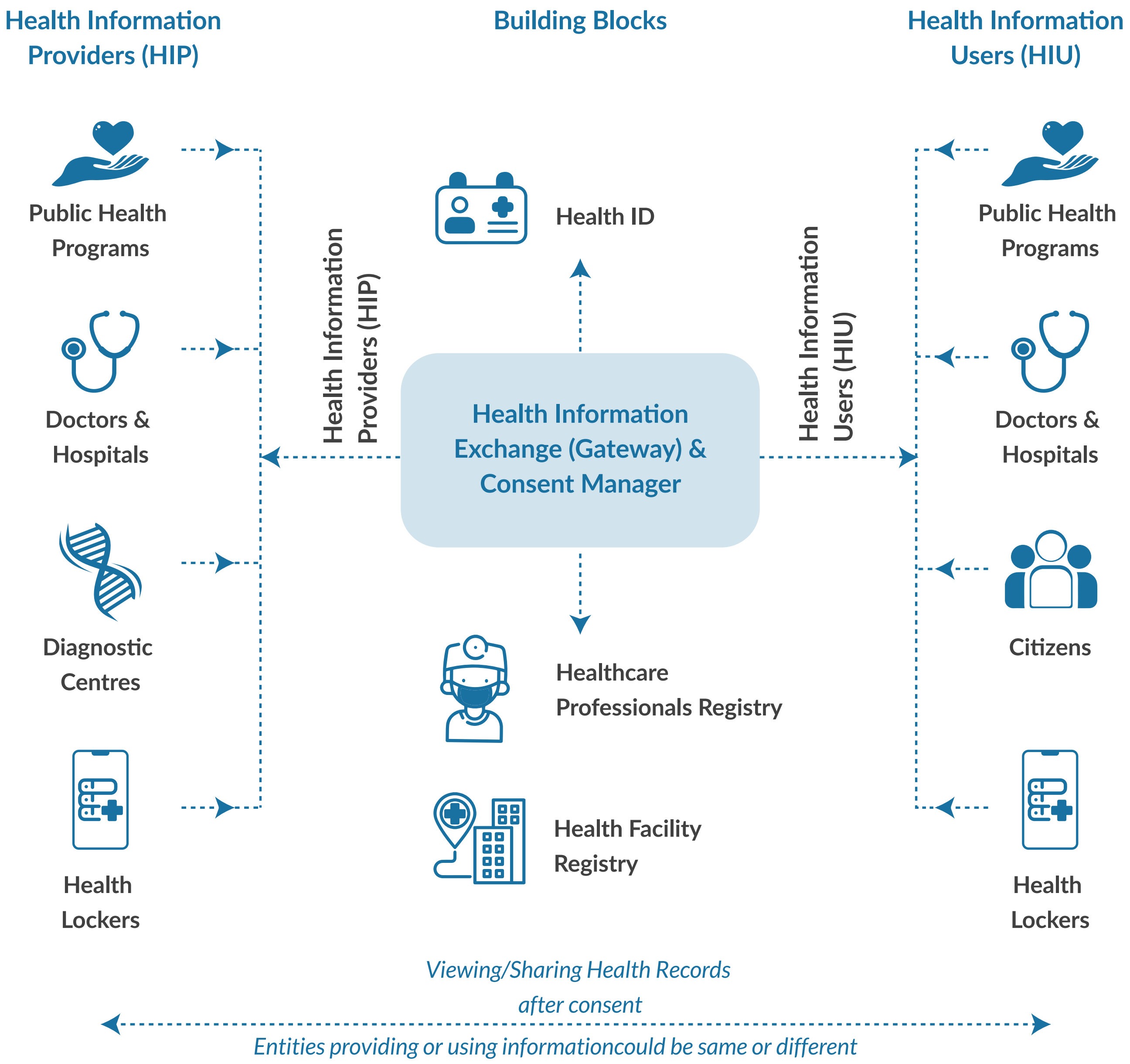


Fig 2 : ABDM Building Blocks (Source: Ayushman Bharat Digital Mission

IV) Unified Health Interface

The concepts like health ID, EHR/EMR (electronic health / medical records) and telemedicine are relatively newer in India compared to other developed countries. Consequently, the penetration of these digital platforms in hospitals and among doctors is low, but growing.

Even during the pandemic, it is seen that doctors are hesitant in picking one specific telemedicine platform for all their patients, and instead use simpler video call applications (like WhatsApp video, Zoom etc.).

Unified Health Interface – creating an open network for digital health services

But such generic communication platforms don't address the administrative aspects of the medical business – like appointment booking, billing etc. To address such issues of vendor lock-in, and in the spirit of creating an open network for digital health services, ABDM has proposed a revolutionary concept called Unified Health Interface (UHI) – among the first in the world for such inter-operable digital services.

UHI ensures that a digital health service can be delivered between any end-user applications (digital app providing telemedicine service, AarogyaSetu etc.) with any health service provider (individual doctors, hospitals, labs etc.) in this ecosystem. This is similar to how users may use different email apps (Gmail, Outlook etc.) and send mails to each other thanks to open protocols (SMTP). Similarly, consumers may use multiple end-user application (BHIM app, PayTM, PhonePe, etc.) to make seamless financial payments from their bank account to any other bank account, thanks to the Unified Payment Interface (UPI).[57]

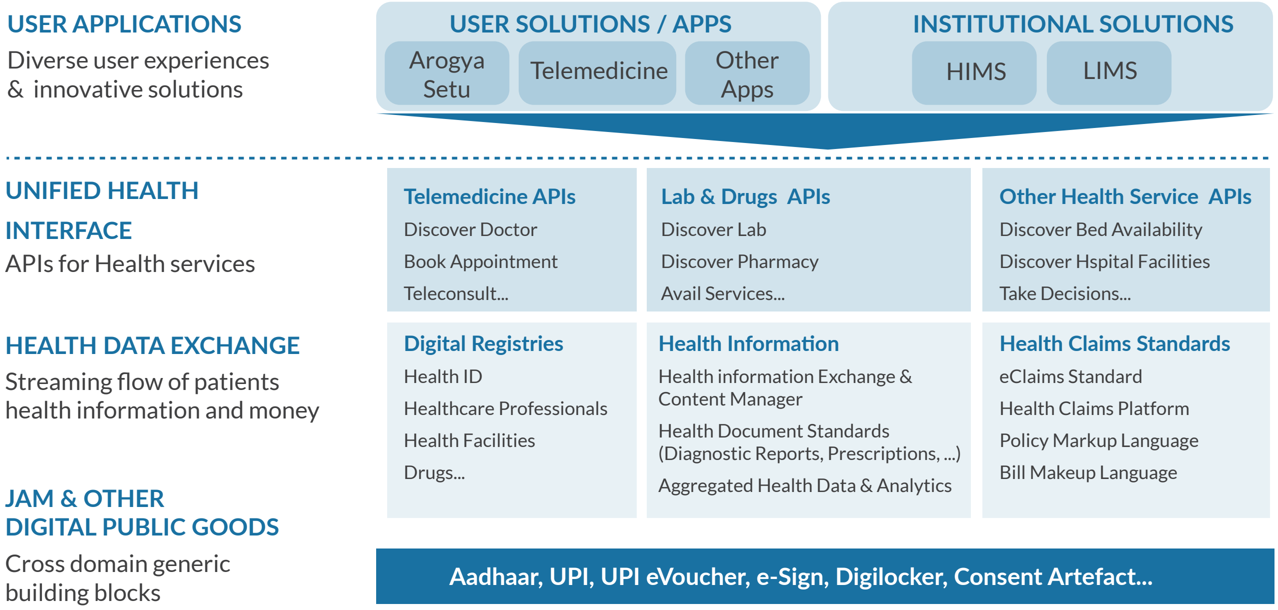


Fig 3 : UHI Layer in the ABDM Architecture (Source: Ayushman Bharat Digital Mission

V) Benefits of the digital health stack

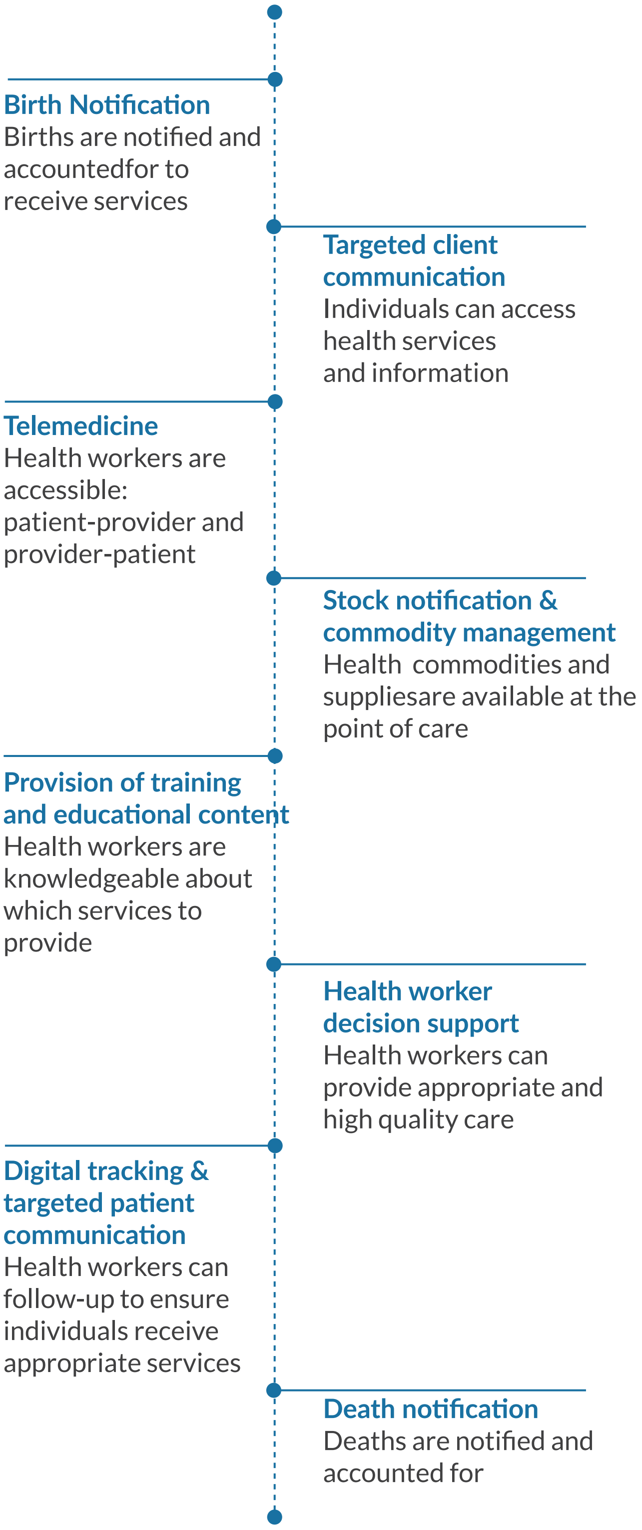
There are several benefits that will accrue to India from such a digital health stack:

- Digital health interventions can help address health system challenges such as geographical inaccessibility, low demand for services, delayed provision of care, low adherence to clinical protocols and costs to individuals/patients. Refer to Fig 2 for WHO's key digital health interventions recommendations.[58]

- The disparate systems will become integrated and healthcare processes will get streamlined.

- More health data is available to both the healthcare provider and the patient, and hence medical care will shift from episodic treatment to a focus on wellness.

- Telemedicine may be the compelling use-case for digital health adoption in India, like Direct Benefits Transfer has been to digital payments. It will allow doctors in cities to consult patients in rural areas, thus alleviating the problem of skewed distribution of healthcare professionals in the country. In villages, community healthcare workers can do an initial assessment using a checklist and then turn to teleconsultation with a qualified doctor. Some estimates suggest that, with telehealth, a doctor can see 1.8X number of patients. The Government's e-Sanjeevani platform (for telemedicine), launched in April 2020, completed over three lakh consultations in a short span of six months.



Birth Notification
Births are notified and accountedfor to receive services

Targeted client communication
Individuals can access health services and information

Telemedicine
Health workers are accessible: patient-provider and provider-patient

Stock notification & commodity management
Health commodities and suppliesare available at the point of care

Provision of training and educational content
Health workers are knowledgeable about which services to provide

Health worker decision support
Health workers can provide appropriate and high quality care

Digital tracking & targeted patient communication
Health workers can follow-up to ensure individuals receive appropriate services

Death notification
Deaths are notified and accounted for

Fig 4 : Key digital health interventions Source: WHO)

Digitisation and interoperability of health data flow will streamline delivery of healthcare. In addition, the digital health stack will also have a transformative effect on health-insurance claims processing. Under the ABDM, the aim is to create a Health Claims Platform as a public platform, where health providers (like hospitals, primary care centres, or diagnostic labs) submit their e-Claims, and insurers and TPAs (third party administrators) receive these claims via standard APIs. Due to such standardisation and usage of electronic means to receive and process claims, the administrative costs will come down. This in turn may spur the introduction of new insurance products that cover OPD (outpatients) too. In the Indian context, where we typically have 100 outpatients and 6-7 in-patients, insurance coverage for OPD will address the affordability challenge of our healthcare system.[59]

Transformative effect of digital health stack on health-insurance claims processing

The ABDM pilot has been launched in the Union Territories of Chandigarh, Ladakh, Dadra and Nagar Haveli and Daman and Diu, Puducherry, Andaman & Nicobar Islands and Lakshadweep. And as of Mar 2021, nearly 10 lakh Health IDs have been issued.[60] In the next few years, as these pilots become full-fledged implementations across the nation, India will witness a digital health transformation.

We need to be vigilant about one aspect – health equity. It has been observed that those at the 'right side' of the digital divide in the society are benefitting much more from using the Internet in every domain than people with the 'wrong side' of the digital divide.[61] We must ensure that the digital divide does not create new forms of health inequities.

3.4. Conclusion – Digital Health Futures

In conclusion, we present seven key trends of digital health that the world will increasingly experience in the next decade.

I) Seven key digital health trends

First, we will see the emergence of Digital Patients and Digital Health Avatars – A digital patient is a lifelong, unified, personalized model of a patient, similar to the idea of a 'digital twin' that is already a reality in manufacturing (for example, a virtual model of turbines or aircraft engines). Our digital patient model is updated with measurements from our fitness trackers, health-sensors, medical examination and tests. All our personal health data will be digital, on the cloud, and controlled by us individually. Given the sensitivity around personal health data privacy, we will be represented online by various types of Avatars in the health-metaverse, and information shared in a consent-based, privacy-protecting manner.

Digital Patients and Digital Health Avatars

Transformative effect of digital health stack on health-insurance claims processing

Second, will be the emergence of digital-first healthcare models. The pandemic has catalysed the adoption of telehealth among both patients and healthcare providers. Digital-first healthcare facilities will expand even for tertiary care services for diseases like cancer. Just like flipped classrooms, we will see the emergence of flipped clinics / hospitals[62] – activities, like collecting samples and running tests, that have typically taken place in clinical settings, will be done in new locations and by leveraging new technologies. Home-based care models will gain popularity.

Consumerisation of Genomics

Third, will be the Consumerisation of Genomics. From an estimated cost of 300 million USD for generating that initial 'draft' human genome sequence in 1999-2000[63] to full genome sequencing at a mere 100 USD in 2020[64], the world of genomics has seen a remarkable transformation. Consumers will increasingly seek genotyping services and CRISPR-based diagnostic solutions at their homes. Some are even comparing this ‘point of care’ CRISPR-diagnostics moment to the PC-revolution in the IT journey.

‘Platformisation’ of biotech

Fourth, biotechnology will become more industrial thanks to the emergence of biotech platforms.[65] During the pandemic, new mRNA-based and adenovirus vector platform-based vaccines have been developed. These platforms would enable ‘plug and play’ model in drug development for other diseases. Such platforms would impact many areas of biotech like small molecule discovery, protein engineering, and cell therapy.

Consumerisation of Genomics

Fifth, a new branch of medicine called Algorithmic Personalised Medicine will emerge. Doctors will collaborate with data scientists to design various types of algorithms (pattern matching, predictive recommender systems etc.) which will consume digital health data of millions of individuals and give personalized medical recommendations to other doctors who are seeing patients. With genomics, big data & AI, wireless sensors, and digital technology revolutionizing every aspect of medicine, the vision of ‘Homo Digitus’ and ‘Deep Medicine’ will become real.[66,67]

Sixth, Health Games will emerge as a new form of medico-social engagement, and millions of people will play these games to help each other and get better. Health games come in various categories[68]

Health Games

– (1) educational games (e.g., informing users about a disease); (2) behavioural games (e.g., improving adherence to medication); (3) cognitive games (e.g., memory training); (4) exercise games (e.g., improving physical exercise); (5) rehab games (e.g., rehabilitation of limbs); and (6) hybrid games (i.e., a mix of others). Health games leveraging technologies like Virtual Reality, 3D modelling, and simulation would be increasingly used in medical education.

Empathic Care Robots

Seventh, Empathic Care Robots will become a reality in hospitals and homes, especially in the care of the elderly and patients with dementia. The AI robots will have the ability to discern human emotions and even display them, understand spoken language, be dextrous enough to give medications, and have an embedded knowledge-base to act as a medical service chatbot.

II) Futuristic digital health scenarios in India

The Indian government's vision for creating a national digital ecosystem is articulated in the 2017 National Health Policy, and ABDM is expected to herald a dramatic transformation of healthcare processes and systems. Also, the pandemic has created an impetus in developing our public health system, with a focus on early identification and prevention of diseases. As these initiatives unfold, India is going to witness a dramatic change in its healthcare system.

We present three futuristic scenarios of digital health in India, from three different perspectives – 1) patient 2) doctor and 3) public health official. We are not offering any probability of occurrence for each of the scenarios. But suffice it to say that the technologies behind each of the scenarios will be available soon. Will societal transformation keep pace?

As we look forward to a world where healthcare professionals and digital systems exist in harmony, we should pay heed to the point that Ralph Engle, a pioneer in computer diagnosis of medical disorders, said in the world's first workshop on AI in medicine in 1975.

> *"The full benefit of the use of computers as tools of thought can come only when we learn to dissect intelligence into a portion best suited to the human being, and a portion best suited to the computer, and then find a way to mesh the two processes."*[69]

Scenario 1 – Digital Health for all – A patient’s perspectives

It is 15 September 2027. Anjali heads to the village hospital for her sixth-month pregnancy check-up. At the reception, she launches her personal health record app on her smartphone and scans the QR code. The hospital registers her based on her unique health ID, and her medical records are made available to her physician.

After the examination, her doctor says: “I want to do a tele-consultation with a senior gynaecologist in the city. Let me log into the eSanjeevani portal.”

The city doctor: “Anjali, before I proceed, I need your consent to access your medical records.”

Anjali approves a request from the city hospital seeking permission for her EMR/EHR stored in the Medi-locker on the cloud.

Anjali: “Doctor, how is it looking? Anything of concern?”

The city doctor: “Here is a summary of the analysis of your medical scans, blood tests, and genetic data by our AI system. There is nothing to worry. Your nutrition intake needs some improvement. I will prepare a diet plan accordingly.”

Anjali’s Medi-locker is updated with the diagnosis summary and treatment plans from the city doctor. And she heads home.

Anjali tells her husband: “Use the DietScan app on my mobile to take a picture of my every meal. The app automatically calculates the nutritional value of my diet, and cross verifies with the dietary plans my doctor has recommended.”

A few months later, Anjali delivers a healthy girl child.

Scenario 2 – Surgery-as-a-Service – A doctor’s perspectives

Dr. Ramesh is all prepped up for this wintry evening of 15 November 2040. It is going to be his 50th “Surgery as a Service (SuAAS)” operation, ever since it was permitted in India. Just like in IT services, where Indian companies manage IT systems of global companies, in SuAAS, doctors in India operate on patients world-wide, from certified hospitals in India leveraging 5G network and robotic surgery. It is already a multi-billion dollar industry in India.

Dr. Ramesh is joined by his medical intern, Dr. Sheila.

Ramesh: “Who are we operating today?”

Sheila: “Our patient is Jill, a resident of Yakima Valley, Washington state, US. We are going to perform a partial hepatectomy and remove a benign tumour.”

Ramesh: “Did you practise for this surgery?”

Sheila: “Fully prepared. Even in my Uber ride to the hospital today, I put on my VR headset and accessed the hepatectomy surgery training module in our hospital system. I practised on the actual scans of Jill’s liver.”

Dr. Ramesh did not want to take any chances with the SuAAS operation. It had been a big struggle in getting global permissions for this service – technology was the easiest part; ensuring standardised EHRs across US and India, agreeing on data sharing protocols, getting the liability and insurance clauses sorted, these were the bigger challenges. But the cost and quality advantage of doing surgeries from India proved too irresistible.

Ramesh: “That’s good. Post the surgery, we will use nanorobots that swim through Jill’s bloodstream to deliver drugs in a highly targeted way at the surgery site. She is not strong enough for a regular full-course of antibiotics.”

Sheila: “Ok doctor. I have spoken to our US hospital partner. We have done a check on the software, on the MRI machine, to control the nanobot. Everything is ready for the surgery.”

Scenario 3 – Community-driven health system – A public-health official's perspectives

A review meeting of the Public Health Informatics and Data Analytics Department, Government of India has been convened on 15 June 2030. Suresh is the Chief Data Officer (CDO) of the department and is chairing the session with his regional Data Czars (DC).

Today is the fifth anniversary of the department. It was created as part of ABDM, and because of the increasingly common occurrence of extreme weather events due to climate change and the raise of vector-borne diseases in our country and the world.

CDO: "How is the flooding situation in the West?"

DC: "The monsoons have been very severe this year, and the multiple cloud bursts sudden. But the flooding situation has abated. We are now tracking the rise of dengue fever cases in multiple containment zones in 7 districts."

CDO: "Trust you are running real-time, virtual simulations of individual neighbourhoods and communities in these zones to track spread of the outbreak?"

DC: "Yes, our models are updated with data from various sources – real-time environmental, biomonitoring, crowd-sourced neighbourhood pollution and water quality data."

Preventive health in the country was no longer organised population-wise or state-wise or age -wise. Citizens received tailored preventive prescriptions from their preferred local primary healthcare providers (both public and private hospitals) who automatedly monitored the citizens' data.

CDO: "Good, ensure that you run the health games and simulations to prepare these communities for any sudden increase in outbreaks."the MRI machine, to control the nanobot. Everything is ready for the surgery."

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