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Applications of Artificial Intelligence (AI) in Indian Healthcare

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Abstract: ***Artificial Intelligence is a field which has been in a continuous process of advancement since its inception over half a century ago. The recent developments in Deep Learning and Neural Networks have brought forth a larger scope of AI applications, with the largest impact arguably being in the healthcare sector. By 2030, when AI is predicted to make up a significant chunk of the world economy, healthcare will be the sector to benefit the most from the adoption of Artificial Intelligence. Many of the present problems which plague the healthcare ecosystem, not only in India but in the rest of the world too, can be tackled to varying extents with the help of AI. For example, using automated screening and diagnosing technology to scan through thousands of MRI scans, time as well as money can be saved. The beauty of most of these algorithms is that their accuracy keeps increasing through self-training as they process more and more data – effectively reducing the need for human intervention. The Indian healthcare ecosystem has suffered from significant under-investment, with only about 3.6 % of total GDP spent on healthcare, much lower as compared to OECD or even BRICS nations. Under India's plan to become an Upper Middle-Income Country by 2030, healthcare is now becoming a priority sector for the Indian government. This paper provides a summary of the complex and multi-layered Indian healthcare system, followed by the scope of AI applications in Indian healthcare in four broad areas, from administration to drug discovery and management. The key challenges and risks associated with AI adoption are also highlighted, along with relevant case studies which have shown promising results. All in all, Artificial Intelligence is ideally suited to enhance the Indian healthcare sector, which is in a dire need of cost-effective, high quality, and scalable solutions.***

Keywords: Artificial Intelligence, AI, Healthcare, Public Healthcare, India, Indian healthcare

AI to contribute USD15.7 Tn to global economy by 2030; Healthcare #1 sector for AI impact.

Artificial intelligence (AI) based applications have already made inroads into many aspects of our lives. Global consultancy firm PwC estimates that AI will contribute USD15.7 Trillion to the global economy by 2030 and that healthcare will be the sector that will experience the greatest impact from adoption of AI *(Sizing the Prize, PwC, 2017)*. India is also expected to be a key beneficiary of adoption of AI with estimated GDP boost of USD450-500 Billion by 2025 *(AI could add $450-500 bn to GDP, Nasscom, 2020)*.

India's healthcare spending very low – 3.6% (of GDP) on overall healthcare & 1.3% on public healthcare

India has traditionally under-invested on healthcare with total healthcare spend (private plus public) at just 3.6% of GDP, which compares poorly relative to OECD countries (US 16.9%, Japan 10.9%) or BRICS countries (Brazil 9.2%, China 5%) (*India needs big dose of health spending, Mint, 2020*). The contrast is even more stark in public healthcare (center plus state) where India spends 1.3% of GDP, compared to OECD countries (US 14.3%, Japan 9.2%) or BRICS countries (Brazil 4.7%, China 3.1%) (*The Bengal Chamber; PwC, 2018*). On per-capita basis, India's public healthcare spend works out to INR1944 (USD27), way below desired levels.

Indian healthcare ecosystem – complex and multi-layered

Indian healthcare eco-system is complex with multiple layers (and significant overlaps). The broad categories of classification are based on: (a) Funding or Ownership source (Govt/Public or Private/Corporate), (b) Location (Urban or Rural), (c) Degree of healthcare delivery / Specialized treatment (Primary, Secondary, Tertiary, Quaternary), and (d) Service category (Hospitals, Diagnostic centers, Clinics). For the purpose of this paper, we have followed the broad classification by ownership, i.e., Public healthcare (owned and operated by Government) and Private healthcare (owned and operated by Private organizations – whether for profit or non-profit organizations).

Healthcare a priority sector – Govt intends to increase public healthcare spending to 2.5% of GDP.

India aspires to become move become a UMIC[1] nation by 2030, which will require India to double its per capita income from the current level of USD2014 (2019). Strengthening the public healthcare system is an imperative to make the move up to UMIC category. Government of India (GOI) is following a three-pronged approach – (a) increase financial outlay, (b) target policy interventions, and (c) leverage technology. GOI has set a target to increase public healthcare spending to 2.5% of GDP by 2025[2].

AI in healthcare – Deep Learning a key enabler + 5 distinct converging trends driving rapid adoption.

Although applications of AI in healthcare started in the 1960s, the momentum really picked up on the back of developments in Deep Learning and Neural Networks. Five distinct trends are converging, driving rapid adoption of AI in healthcare; these are (a) value challenge, (b) explosion in amount of health data, (c) developments in information technology, (d) democratization of access, and (e) willingness of general public *(What Doctor, PwC, 2018)*.

AI in healthcare - multiple applications in 4 broad areas

AI applications in healthcare are multi-fold and ever expanding. Currently, the areas within healthcare where AI-

[1]Upper Middle-Income Country
[2]National Health Policy (2017)

based applications have already made meaning full impact can be divided into four broad categories – (a) administrative services, (b) screening & diagnosis, (c) treatment, nursing & monitoring, (d) drug discovery & medicine management.

5 key challenges & risks in AI adoption in healthcare

While AI applications in healthcare can undoubtedly benefit humankind by providing accessible, affordable, and high-quality healthcare, we should also be cognizant of the associated challenges and risks involved. In our view, the 5 key challenges and risks are (a) privacy, ethics, and data security, (b) biases and prejudices associated with historical data may get perpetuated, (c) training of machines need to be population specific, (d) adversarial attacks can give rise to rogue machines, and (e) medical training needs to incorporate data and informatics literacy.

We highlight 3 case studies covering screening, testing and hospital management.

We have highlighted three cases studies in this paper where AI-led pilots have either already demonstrated significant benefits or exhibit significant promise. Google and Verily have combined with two eye hospitals in India to scale up screening for Diabetic Retinopathy. Mumbai's municipal body is currently running a pilot to test efficacy of AI-based voice sample screening for COVID-19 infection, using a smartphone app. Narayana Health, a leading Indian hospital chain, working towards its mission of providing affordable and high-quality healthcare, has employed AI tools that have provided promising results in areas such as hospital administration, nursing, lab tests, radiology, and surgery costs.

Public healthcare in India requires cost-effective solutions at scale – AI ideally suited.

As a developing economy, India has to balance the competing demands on its resources in terms of developing physical and social infrastructure to improve the lives of its citizens. Given the scale of its public healthcare system and large population, India has to find innovative solutions that are (a) cost-effective, (b) rapidly scalable, (c) high-quality, and (d) cognizant of India's shortage of doctors and other nurses. AI-led solutions are ideally suited to mitigate all these challenges and hence AI is likely to play a very important role in India's aspiration to scale up its healthcare system, especially public healthcare.

AI-led healthcare solutions have the potential to power India's journey to an UMIC nation by 2030.

In conclusion, we are of the firm opinion that AI holds great promise for revolutionizing healthcare globally during the coming decade. India will have to focus on healthcare in general, and public healthcare in particular, to fulfill its aspiration of becoming an UMIC[3] by 2030. AI-led solutions will undoubtedly play a very important in powering this journey and improving the lives of India's citizens.

1. Introduction

Artificial intelligence (AI) based applications have already started to make very meaningful impact in revolutionizing the way healthcare services are delivered. Global consultancy firm PwC estimates that AI will contribute USD15.7 Trillion to the Global Economy by 2030 and that the sector that will experience the greatest impact of AI is healthcare.

With this background, we set out to study the way AI is likely to transform the healthcare sector in India, with special focus on public healthcare.

The ongoing CoVid-19 led global pandemic has exposed the structural weakness in public healthcare systems in most countries across the globe. The challenges in India have been further accentuated by decades of under-investment in healthcare, especially public healthcare.

Even before the CoVid-19 pandemic hit the country, the Government of India had recognized that the public healthcare system needs strengthening and had announced significant financial and policy-led support to aid that process.

In this paper, we have outlined the Indian healthcare eco-system – public and private healthcare, current levels of spending and likely scenario going forward.

We have also looked at key drivers enabling the growth of AI applications in healthcare, the various areas where such applications are being pursued and the challenges / risks posed by adoption of AI in healthcare.

Lastly, we have highlighted three case studies where AI-based applications and tools are being used in the healthcare sector in India. All three case studies highlight how AI has demonstrated very promising results, which when applied on scale have the potential to deliver quantum benefits that a country of India's size needs.

We believe that rapid adoption of AI-based applications in healthcare is an imperative that will greatly improve the lives of India's 1.4 billion citizens.

2. India's Healthcare Landscape – A Snapshot

India spends 3.6% of GDP on healthcare, way below the norm in most prominent countries

India's total healthcare spending (out of pocket and public) is just 3.6% of GDP, way below that of other countries *(India needs big dose of health spending, Mint, 2020)*. The average for OECD countries was 8.8% of GDP. Amongst developed countries the prominent ones are US (16.9%), Germany (11.2%), France (11.2%) and Japan (10.9%). Even among BRICS countries, healthcare spends are higher as a percentage of GDP – Brazil (9.2%), South Africa (8.1%), Russia (5.3%) and China (5%).

[3]Upper Middle-Income Country

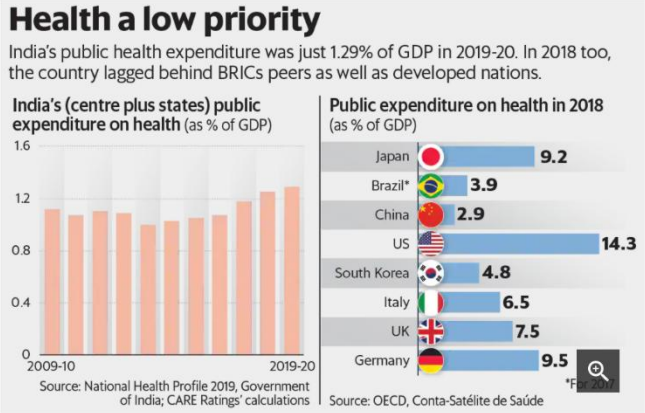


Exhibit 1: Public healthcare spending in various countries (source: Mint)

Public healthcare expenditure just 1.3% of GDP; States account for 75% & Centre 25%

The picture is even worse as far as India's spending on public healthcare (centre plus states) is concerned at just 1.29% of GDP, way below developed countries (US 14.3%, Germany 9.5%, Japan 9.2%) or even BRICS countries (South Africa 4.3%, Brazil 3.9%, Russia 3.2%, China 2.9%). Of the total expenditure on public healthcare, the centre contributes to about 25% with the states contributing the balance 75%.

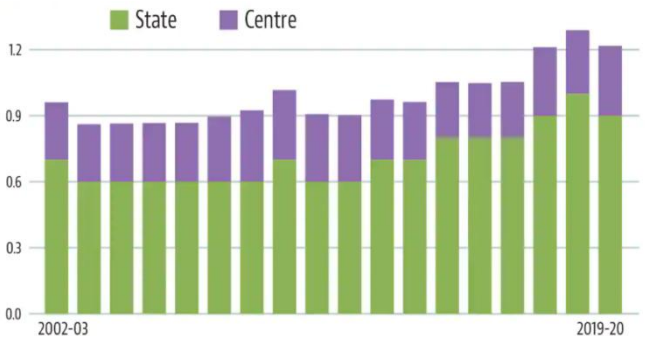


Exhibit 2: Share of Centre & State in public healthcare spending in India (%age of GDP) – FY03 to FY20 (Source: Hindustan Times, Mint)

Govt's per capita spending on healthcare grew 2X in 5 years, but still low INR 1944 (USD 26)

Although the total per capital government spending on healthcare in India has nearly doubled over the last 5 years, from INR 1008 (2014-15) to INR1944 (2019-20), in absolute terms the current spend remains very low. Incidentally, this spend includes the entire govt spending (salaries, budgetary support to various institutions, hospitals, and transfer to states under centrally sponsored schemes).

Shortfall in doctors (35%) & nurses (48%) relative to WHO's recommended norms.

India has 0.65 doctors per 1000 people, well below WHO recommended norms of 1. The shortfall is even more stark in the case of nurses where there are 1.3 nurses per 1000 people compared to the WHO recommended norm of 2.5.

Hospital beds 73% below WHO's recommended norms.

Even in terms of physical healthcare infrastructure, India fares poorly with just 1.3 hospital beds per 1000 people, compared WHO's recommended number of 3.5

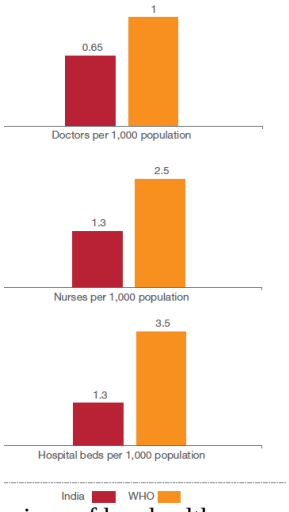


Exhibit 3: Comparison of key healthcare resources, India vs WHO recommended norms (Source: WHO, NSS, PwC)

3. India's Healthcare Eco-System

Healthcare provider eco-system is multi-layered and complex.

Healthcare service provider eco-system in India is complex with multiple layers (and significant overlaps). The broad categories of classification are:

(a) Funding or Ownership source (Govt/Public or Private/Corporate)
(b) Location (Urban or Rural)
(c) Degree of healthcare delivery / Specialized treatment (Primary, Secondary, Tertiary, Quaternary)
(d) Service category (Hospitals, Diagnostic centers, Clinics)

The broad distinction of Public and Private Healthcare

For the purpose of this paper, we will follow the broad classification by ownership, i.e., public healthcare (owned and operated by Government) and private healthcare (owned and operated by Private organizations).

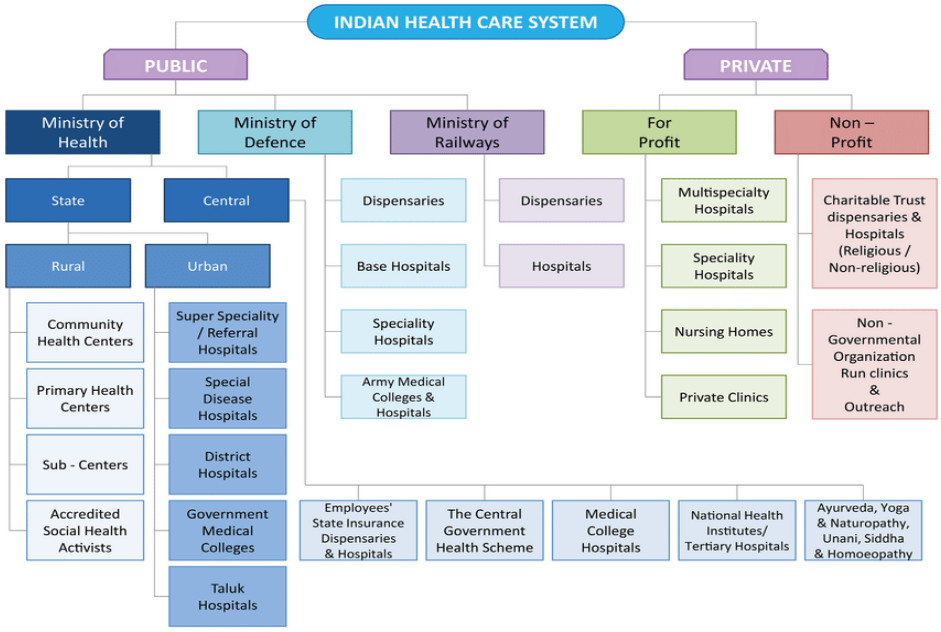


Exhibit 4: Indian healthcare eco-system (Source: dristiias.com)

3.1 Public Healthcare System

Public healthcare, the backbone of the healthcare system, is free or highly subsidized.

Historically, healthcare delivery has largely been under the purview of the government - center, state, or local municipalities. Some of the prominent examples of government hospitals are All India Institute of Medical Sciences (Delhi), Tata Memorial Hospital (Mumbai) etc. At the primary healthcare level, the dominance of public healthcare is even more pronounced. In general, public healthcare is either free or significantly subsidized by the state.

Classification of public healthcare system

The various sub-categories within public healthcare are:

Primary healthcare

Primary health centers (PHC) are the most basic unit of healthcare centers run by state governments. These are usually situated in rural or semi-urban areas, although there are some PHCs in urban areas as well. PHCs tend to be the first port of call for patients.

PHCs are usually staffed with one doctor (or in some cases one doctor may be shared by two PHCs) and a nurse/mid-wife. Some of the focus areas for PHCs are infant immunization program, anti-epidemic programs, birth control programs, pre-natal and neo-natal care, medical emergencies.

In case of minor ailments, which would be the majority of cases, most patients would get treated at PHC level. However, for more serious ailments patients would be referred to secondary or tertiary healthcare establishments. Even for emergency cases, the effort would be to try and stabilize the patient at the PHC before transferring her to the nearest hospital.

Exhibit 5: A typical Primary Healthcare Centre

Secondary healthcare

Secondary healthcare is a step above primary healthcare in terms of degree of specialization of doctors and/or quality of medical infrastructure. A patient would typically be referred to a secondary healthcare centers (SHC) by the doctor at the PHC, for further diagnosis and/or treatment.

Each SHC would cover a few PHCs in that geographical area and typically SHCs are situated in semi-urban areas rather in in rural areas.

However, over time, as quite a few of the PHCs have got upgraded, both in terms of availability of healthcare professionals and physical/medical infrastructure, SHCs are gradually becoming redundant and patients are increasingly being referred to District Hospitals, which would fall in the domain of tertiary healthcare.

Tertiary healthcare

(a) District Hospitals

Administratively, Indian states are divided into districts and each district is further sub-divided into sub-districts (known

as talukas or tehsils). The first level of tertiary care is a hospital at the district or taluka level. These hospitals provide both outpatient department (OPD) care and in patient (or hospitalization). The size/scale of these District Hospitals (in terms of number of beds, number of doctors and nurses, number of medical specializations catered to) are defined by the population of the catchment area and the type of medical conditions/diseases prevalent in that area.

Exhibit 6: A typical District Hospital.

(b) Teaching Hospitals

As per regulations of the Medical Council of India (MCI)[4], all medical colleges in India need to have an associated teaching hospital. These hospitals serve dual purpose – (i) provide students with the opportunity to learn by observing and treating real life cases, and (ii) provide patients with "affordable" healthcare. Teaching hospitals can be Govt owned (e.g., Maulana Azad Medical College, Delhi) or Private owned (e.g., Kasturba Medical College, Manipal). However, irrespective of the ownership structure, teaching hospitals constitute an important element of the public healthcare system by virtue of its "affordable" characteristic.

(c) Other hospitals include Defense, Railways, ESI etc.

Additionally, there are hospitals and clinics that cater to a defined group of people, usually employees (and their families) of very large government employers. Examples are: Defense hospitals (for defense forces), Railway Hospitals (for railway employees), Employees' State Insurance or ESI Hospitals (a self-financing social security and insurance scheme administered by the government).

Quaternary healthcare

Super specialty hospitals that offer treatment across a large number of medical specializations and have exceptionally large capacities (in terms of healthcare professionals, medical equipment etc.) are classified under quaternary healthcare. Many of these hospitals also tend to be centers of excellence and research institutes. One of the most prominent quaternary care centers in India is AIIMS[5].

3.2 Private Healthcare System

Private sector now accounts for majority of hospital capacity

Over time, as successive governments (both center and state) have underspent on healthcare and demand has increased for healthcare services due to growing population, private sector has stepped in to fill the gap. This is especially so in the case of Tertiary and Quaternary care hospitals where private sector accounts for a disproportionate share of incremental hospital beds added over the period 1990-2020.

Affordability a big challenge in private healthcare

Private healthcare, especially in hospitals, is beyond the reach of large portion of the Indian population. Over the years, significant cost inflation in all elements of a hospital's cost structure (real estate, building infrastructure, rapid upgradation of medical equipment, salaries of doctors, medical and non-medical staff) has meant that even the need for "reasonable profit" for a private hospital puts its services beyond the paying capacity of a large section of society.

The four categories of care in private healthcare

Similar to the public healthcare system, the private healthcare system also has presence across the following four segments of the care.

Category of care	Format
Primary care	Private clinics
Secondary care	Nursing homes
Tertiary care	Hospitals
Quaternary care	Multi-specialty / Super-specialty Hospitals

Classification of private healthcare system along profit motive

The most relevant classification of private healthcare system would be on the lines of ownership/profit motive. Private healthcare systems can be broadly sub-divided into two categories – (a) Non-Profit, and (b) For Profit.

(a) Non-Profit

Some of the more prominent private hospitals were started under charitable trust structure, by either a wealthy philanthropist or business house (e.g., Hinduja Hospital, Mumbai). These are meant to be run as "not for profit" institutions. In most cases, these trusts have been provided by free/subsidized land by governments and the trusts are supposed to provide free/subsidized treatment to a certain portion of patients, as mandated by the governments. The trusts are supposed to achieve this objective by following a policy of cross subsidization whereby they charge commercial rates to a larger part of the patient body and utilize the surplus so generated to provide free/subsidized service to the relatively more under-privileged sections of society.

However, many (if not most) of these hospitals do not fully comply with the spirit of these regulations. As a result, access to medical care at these hospitals is beyond the reach of a very large section of the country's population.

(b) For Profit

Since the 1980s, a few hospital chains under corporate structures (i.e., these are run as for-profit entities) have

[4]Medical Council of India (MCI) is the regulatory body for medical education in India.

[5]All India Institute of Medical Sciences (AIIMS) performs multiple functions – medical college, research institute, outpatient care and in-patient care across multiple medical specializations.

come up and have grown rapidly since then. These can be national chains (e.g., Apollo Hospitals) or strong regional players (e.g., Manipal Hospitals in the South) or prominent city-based hospitals (e.g., AMRI Hospitals in Kolkata).

4. Healthcare - A Priority Area For Government

During the course of the current decade, India aspires to move up from the category of lower middle-income country (LMIC) to upper middle-income country (UMIC)[6]. In order to do so, India will have to double its per capita income from the current level of USD2,014 (2019). Strengthening the public healthcare system is an imperative to make the move up to UMIC category.

Additionally, India is also a signatory to Sustainable Development Goals (SDG) 2030 of the United Nations Development Programme (UNDP). SDG outlines a set of 17 goals that all member countries should strive to attain to make the lives of their citizens better. One of the key goals in SDG is improving quality of healthcare *(Sustainable Development Goals, UNDP, 2015)*.

Exhibit 7: Sustainable Development Goals 2030 (Source: UNDP)

In order to improve healthcare eco-system in the country, the Government of India (GOI) has identified public healthcare as a priority area. GOI is following a three-pronged approach – (i) increase financial outlay, (ii) target policy interventions, and (iii) leverage technology.

(i) Increase in financial backing.

Spend on public healthcare set to rise to 2.5% of GDP by 2025.

In its National Health Policy 2017, the Government of India has set a target to almost double the spend on public healthcare (as a percentage of GDP) to 2.5% by 2025[7]. Some of the key elements of this drive towards higher focus on public healthcare are the following schemes.

(ii) Target policy interventions

Pradhan Mantri Jan Arogya Yojana (PMJAY) – Launched in September 2018, PMJAY provides for cashless health insurance cover of up to Rs500,000 per year for 100 million families (covering approximately 500 million citizens)

Ayushman Bharat – Ayushman Bharat program envisages setting up / upgrading existing PHCs to health and wellness centers by 2022. These centers will have special focus on prevention and control of diseases and medical conditions such as diabetes, hypertension, cancer, and age-related illnesses.

Mission Indradhanush –Mission Indradhanush aims to achieve full immunization, across all available vaccines, of all children up to 2 years of age and all pregnant women, in both rural and urban areas.

National Digital Health Mission (NDHM) – In 2020, GOI announced the launch of NHDM, a unified healthcare program under which the government will issue a digital health ID for every citizen *(What is digital health ID, NDTV, 2020*). This will be a 14-digit unique health ID for each individual and will allow the individual to share his health-related data with various healthcare players such as doctors, hospitals, insurers etc.

District Residency Programme (DRP) – DRP envisages a 3-month mandatory residency stint at District Hospitals for all Post-Graduate (PG) Medical students as part of course curriculum, effective academic year 2020-21[8]. The objectives of this plan are (a) expose all medical students to the public healthcare system, and (b) partially address the shortage of doctors in public healthcare services.

(iii) Leverage Technology

The Union Health Ministry has prioritized building AI technology capabilities to address gaps in the public healthcare system. Applications of AI will enable India to scale up healthcare delivery in a cost-effective manner – widening reach and access to quality healthcare services for large sections of the population (*Health Ministry to use Artificial Intelligence in safe way in public health, 2019)*.

The following examples provide a flavor of initiatives being undertaken by GOI to leverage AI:

(a) Creation of Imaging Biobank for Cancer for which NITI Aayog along with Department of Biotechnology is building a database of cancer related radiology and pathology images for early and reliable screening of cancer.
(b) NITI Aayog is working on using AI tools for early detection of Diabetic Retinopathy.

[6]World Bank categorizes countries based of per capita income into four groups – high, upper-middle, lower-middle, and low; lower-middle income countries are those with per capita income in the range of USD1,026-3,995.

[7]https://economictimes.indiatimes.com/news/economy/policy/india-to-increase-public-health-spending-to-2-5-of-gdp-pm-modi/articleshow/67055735.cms?from=mdr

[8]https://www.outlookindia.com/newsscroll/three-months-posting-at-district-hospital-mandatory-for-pg-medical-students/1939384

5. AI in healthcare – rapid adoption & key drivers

AI to contribute USD15.7 Tn to Global Economy by 2030; India also likely to be a key beneficiary.
Artificial intelligence (AI) has made its presence felt in various aspects of life. Global consultancy firm PwC estimates AI to contribute USD15.7 Trillion to the Global Economy by 2030 *(Sizing the Prize, PwC, 2017)*. India is also expected to be a key beneficiary of adoption of AI with estimated GDP boost of USD450-500 Billion by 2025 *(AI could add $450-500 bn to GDP, Nasscom, 2020)*.

Healthcare sector leads in adoption of AI.

Exhibit 8: Potential AI impact on various sectors (Source: PwC AI Impact Index)

AI has already made significant impact in healthcare and has the potential to positively impact the lives of all the 7 billion plus people currently living on this planet and much more so for future generations to come.

AI in healthcare has a 6-decade long history, but applications have been fairly basic for most part.
Applications of AI in healthcare are not new. The first application of AI in healthcare was in 1964 with Eliza, the very first chatbot, which was a conversational tool that recreated the conversation between a psychotherapist and a patient *(Siwicki, 2020)*.

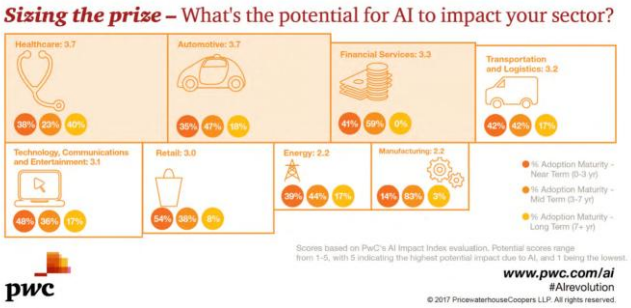
However, most part of the last 50 odd years, AI applications in healthcare were relatively basic in nature, compared to the rapid strides which have been made over the last 5-8 years.

Rapid adoptions of AI a more recent phenomenon, driven by 5 distinct trends are converging.

Five distinct trends are converging, driving rapid adoption of healthcare *(What Doctor, PwC, 2018)*:

(a) **Value challenge** - escalating challenge from long-term, chronic disease, rising costs, often with an ageing population and limited resources.
(b) **Explosion in the amount of health data** – humongous amount of health-related data (a very significant chunk of which is in unstructured form) that is well beyond the scope of any human to process.
(c) **Developments in information technology** –rapidly moving from medical products (equipment, hardware, consumables) to medical platforms (wearables, big data, health analytics) to medical solutions (AI, robotics, virtual and augmented reality)
(d) **Democratization of access** – created by the explosion of technology that is digitally enabled and wirelessly connected across increasingly mobile devices; some of the most powerful AI tools are already embedded in Android or iOS.
(e) **Willingness of general public** – people are more active participants in their health and wellness; acceptance of AI intervention in healthcare is increasing, more so in countries with relatively weaker healthcare infrastructure.

The *PwC AI Impact Index*, which identifies eight sectors with the biggest potential for AI impact, places healthcare right at the top amongst all these sectors *(Sizing the Prize, PwC, 2017)*.



Developments in AI from Machine Learning to Deep Learning acted as key enabler
Medical data has been accumulating in the healthcare system with hospitals and other medical delivery centers over the last 30-40 years, especially so after computers have become ubiquitous in most healthcare setups. Hence, we now have *massive amounts of data at scale in electronic form* (no need to do manual entry of data anymore).

However, till recently, usage of AI in healthcare was fairly limited and quite basic in nature. What really provided the required boost to, and wide-ranging applications of, AI in healthcare services was the development of, and rapid progress in, Deep Learning (DL) and Neural Networks (NN).

Prior to the development of DL, what was available to practitioners of AI was Machine Learning (ML). ML was not powerful enough to process the high dimensional data that is available in healthcare and thus we had to wait for the development of DL for the full potential of AI in healthcare to be unleashed.

In other words, to put in simply, the availability of massive amount of the high dimensional data in healthcare was the "necessary" condition, but it was not "sufficient" till the advent of DL and NN.

AI applications target 4 broad areas of healthcare
Applications of AI in healthcare are multi-faceted and ever widening. The areas within healthcare where AI tools are currently being used can be broadly divided into four broad categories – (a) administrative services, (b) screening & diagnosis, (c) treatment, nursing & monitoring, (d) drug discovery & medicine management (*Sinhasane, 2019*). This is elaborated in greater length in the next section (AI – areas of application, page 19).

AI systems are getting smart, sometimes smarter than human healthcare practitioners
AI-based systems, when "trained" appropriately, have a very steep learning curve. Additionally, the ability of these systems to process data at scale by matching or comparing sample data with reference data stored in the data bank, puts AI systems at significant advantage vis-à-vis humans. Over

time, these machines can learn to become smarter – to get at par with human healthcare practitioners in certain areas. In our case study cited later in this paper (page 23) we have indicated how in Google's pilot project with two Indian eye hospitals, the accuracy of AI-based systems (used to screen retinal images for Diabetic Retinopathy) were initially at par with those of General Ophthalmologists (Dec 2016) and later improved further and were at par with those of Retinal Specialists (Feb 2018).

Huge shortage of trained medical practitioners will drive faster adoption of AI.

Globally, there is a shortage of health care professionals. The situation is even more acute in India as indicated earlier (India's healthcare landscape – a snapshot, page 6). AI tools can play a very important role in addressing these shortcomings by becoming very meaningful force multipliers.

COVID-19 makes AI adoption even more urgent.

The current CoVid-19 global pandemic, which presents multiple challenges to the healthcare sector, is also a unique opportunity to rapidly scale up adoption of AI tools in healthcare. AI applications in COVID-19 can be used for proper screening, analyzing, prediction and tracking of current patients and likely future patients (*Vaishya, Javaid, Khan, & Haleem, 2020*).

6. AI in Healthcare – Areas of Application

Applications of AI in healthcare are multi-faceted and ever widening. The areas within healthcare where AI tools are currently being used can be divided into four broad categories – (a) administrative services, (b) screening & diagnosis, (c) treatment, nursing & monitoring, (d) drug discovery & medicine management (*Sinhasane, 2019*).

Administrative services

1) Administrative assistants – AI-enabled administrative assistants help healthcare providers deal with administrative matters, which although essential part of running a hospital, are not strictly in the domain of medical care. This enables doctors and nurses to focus on the medical aspect of their jobs, by freeing up their time currently being used in non-medical activities. It allows for an easier integration process with the existing technological infrastructure. It can help keep a record of all treatments and patients to allow predictive diagnosis.
2) Cyber security – Patient data privacy is increasingly becoming a critical area that all healthcare providers must focus on. AI cyber security applications provide an extra layer of security to keep patient data safe and prevent unauthorised access and misuse.
3) Fraud detection - As medical costs are rising, instances of fraud, especially related to insurance cases, too are rising. AI tools are ideally suited to mine the vast amounts of data being generated to detect warning signs of deviation from the norm, which could be red flags for fraud.

Screening & Diagnosis

1) Automated image screening – One of the most exciting applications of AI has been in the area of screening. The ability of deep learning models and neural networks to screen thousands of medical images in seconds is a very powerful tool in widening the reach of healthcare, especially in screening for diseases like diabetes, cancer etc. This has special benefits in the area of public healthcare.
2) Preliminary diagnosis – Proper diagnosis is the first to successful treatment outcome in medicine. AI tools have made significant impact in the area of diagnosis, and over time these tools have become extremely sophisticated as they have "learnt" progressively and the quality of diagnosis is now in most cases at par with the best of physicians, and in some cases even superior.

Treatment, Nursing & Monitoring

1) Robot-assisted surgery - AI-enabled surgical robotics can improve surgical procedure, after mining useful information from real life surgeries, thereby reducing total treatment time, minimising errors, and increasing cost-effectives.
2) Virtual nursing assistance – Virtual nursing assistants can act as force multipliers for healthcare professionals, thereby reducing patient load at hospitals. AI-enabled virtual nursing assistants can act as 24X7 bridge between patients and healthcare providers, with only non-routine escalations for human intervention.
3) Treatment design – Complex AI systems meant to store and analyse vast amounts of data already exist in the healthcare sector. These are in the form of patient records, clinical procedure, research etc. AI tools can distil this data and arrived at customized treatment for a patient.
4) Digital consultation - AI-based applications offer the ability to provide medical consultation, based on common medical knowledge combined with the personal medical history of the patient. Users can enter their symptoms into the app, which then uses the speech recognition technology to compare the received data with a database of illnesses. Based on this consultation, the application can suggest appropriate treatment.
5) Health monitoring – Smart wearables with embedded AI technology are already in use to keep track of a patient's health. Devices such as Apple Watch can on real-time basis monitor the heart rate and the activity levels of the user. These devices can also send alerts and notifications to the user and/or other connected individuals, like a close relative or doctor, in case of impending medical emergencies, thus improving chances of positive outcome.
6) Connected machines - Medical institutions today largely function on a variety of connected devices which are able to relay information to one another. Artificial Intelligence can make this process safer and more intuitive. It also helps in consolidating data for further analysis.

Drug discovery & medication management

1) Drug discovery - One of the greatest challenges in the pharmaceutical industry is the long and expensive process of drug discovery. AI applications can make the drug discovery process significantly more efficient in terms of both money spent and time required. This will

also ensure that drug discovery process is pursued for even orphan diseases[9] which are currently neglected.

2) Clinical trial participation – Clinical trials for a new drug goes through four different phases and an enormous amount of data is generated through each phase. All this data needs to be collated and organised in a coherent fashion to derive the "correct" outcome. AI applications are ideally suited to facilitate this outcomes-driven approach of clinical trials.
3) Medication management - AI applications can be used to monitor the use of medication by patients. There is a webcam arrangement which automatically relays information regarding how a patient is taking their prescription medicines. This also helps in better management of the condition if it is serious.
4) Dosage error reduction - Even a little drop of medicine can make a huge difference. So, it is important to keep the dosage of a patient absolutely perfect, or else there might be reparations to pay. The application is designed to reduce the margin of medical errors that may occur when giving medicines to patients.

7. AI in healthcare - Challenges & risks

Privacy, ethics, and data security pose key challenges.
Privacy, ethics, and data security are going to be key issues associated with AI applications in healthcare (*Mahapatra, 2019*). Hence, any applications of AI have to build in adequate safeguards to address these key concerns. Failure to do so will lead to quick disenchantment with AI and result of stymieing the growth of AI in healthcare, despite all its known benefits to humankind.

AI based on historical data, biases and prejudice may get perpetuated.
Machine Learning or Deep Learning as a practice is predicated on learning from historical data. Hence, there is a risk that some of faulty historical data or biases can get ingrained in the system and over time these can get more self-perpetuating in nature (*Harvard, 2019*).

Training of machines need to be population specific.
AI models work on the basis of data inputs provided to the machines. If a machine is trained basis the data relevant to one part of the world and then those learning's are applied in another region where disease profile, genetics etc. might be different, it is likely to lead to incorrect or undesirable outcomes. Hence, it is important to train machines of the data relevant to the population of the region where it is sought to be applied (*Harvard, 2019*).

Adversarial attacks can create rogue machines.
Adversarial attacks – manipulating tiny pieces of data can alter behavior of AI systems, can lead to the creation of rogue machines. For example, changing a few pixels on a lung scan can potentially mislead an AI-led application to arrive at a faulty diagnosis, either detecting an illness where there is none or not detecting one where exists. One concern is that hackers could potentially make these alterations. A more serious concern could be handing over that power to doctors, hospitals and other organizations to manipulate AI in billing or insurance software in order to maximize their earnings *(Warnings of a Dark Side to A.I. in Health Care, NYT, 2019*).

Medical education curriculum needs to incorporate data and informatics literacy.
Given the increasing application of AI in healthcare it is becoming essential to incorporate data/informatics literacy in medical education. Dr Nigam Shah, Associate Professor of Medicine (Biomedical Informatics) at Stanford University, recommends "making Data Literacy and Informatics Literacy a core curriculum, and not an optional item" in all medical schools. as part of training for all students (*Stanford, 2019*).

7.1 Case Study 1 – Google's Project In Diabetic Retinopathy Screening

Google has been working with 2 Indian hospitals on implementing AI-based applications.
In 2015, Google and Verily[10] started a pilot program with two well-known Indian eye hospitals – Aravind Eye Hospital and Shankara Nethralaya to test AI-based applications in the area of ophthalmology. The projects involved using AI-based tools to screen for diabetic retinopathy. The initial results were very promising, and the pilots have subsequently been scaled up *(Bringing AI and machine learning innovations to healthcare (Google I/O '18), 2018*).

Diabetic retinopathy – leading cause of blindness; 45% patients suffer vision loss before diagnosis.
India, with over 70 million diabetes patients, is considered the diabetes capital of the world. Diabetic Retinopathy (DR) is the fastest growing cause of blindness – something that is completely preventable if detected in time. Google's study indicates that about 45% of patients suffer vision loss before diagnosis.

AI enables screening at scale, addressing issues of accessibility and affordability.
A key reason for the large number of DR led blindness is lack of access to eye specialists for large sections of the population in India, especially so in rural and semi-urban areas. It is estimated that India has a shortage of 127,000 eye doctors. AI applications enable screening at scale, addressing issues of both accessibility (image of patient's retina is captured and sent electronically to AI-based screening machines) and affordability (machines can screen multiple images in the time taken by an eye doctor to screen one patient, thus bringing down per patient cost).

AI accuracy levels at par with Retinal Specialists
AI's accuracy of diagnosis improved rapidly from being on par with General Ophthalmologists (Dec 2016) to being on par with Retinal Specialists (in Feb 2018). The accuracy

[9]Orphan disease is a rare disease whose rarity means that the potential market is not large enough for drug discovery to be commercially viable for pharmaceutical companies.

[10]Verily Life Sciences is Alphabet Inc.'s research arm focused on life sciences.

levels were high on both parameters - Sensitivity[11] and Specificity[12].

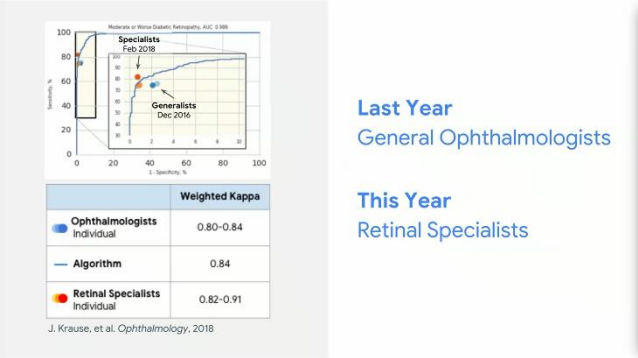


Exhibit 9: Accuracy of AI systems in detecting Diabetic Retinopathy vs Doctors (Source: Google I/O '18)

The same retinal scans can be used to predict cardiovascular risks by a non-invasive method.

While the primary objective of the project was to analyze efficacy of AI in screening for DR, the AI systems offered more insights into a seemingly unrelated field. The same retinal scans used for diagnosis of DR could now be used by the AI systems to predict the risk of an individual to have an adverse cardiovascular event – heart attack or stroke, over the subsequent 5-year period. Based on a just retinal scan, the AI system could predict, with very high degree of accuracy, parameters such as age, sex, smoking habits, blood glucose levels, body mass index and blood pressure. This now opens the door to a new non-invasive method to detect cardiovascular risk *(Sundar Pichai on the application of AI in healthcare (Google I/O 2018), 2018*).

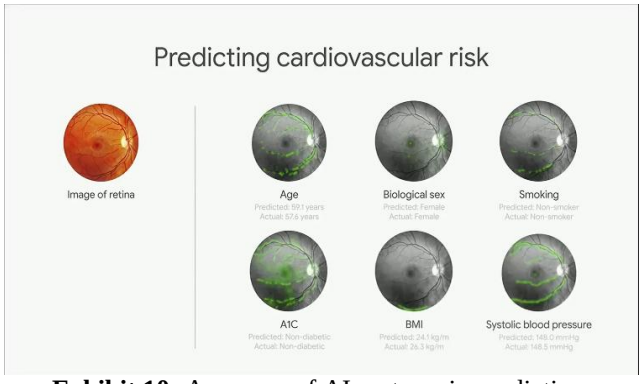


Exhibit 10: Accuracy of AI systems in predicting cardiovascular risks based on retina scan (Source: Google I/O '18)

Pilot has proven benefits for public healthcare – quality, scalability& cost effectiveness.

By bringing expert diagnosis to places where trained specialists are scarce, these pilots by Google and Verily have demonstrated the ability to successfully implement AI-based applications to deliver healthcare service that is (a) of high quality, (b) rapidly scalable, (c) cost effective. All these elements are ideally suited to be deployed in the quality public healthcare system that India aspires to bring to its citizens.

7.2 Case Study 2 – Mumbai Municipal Body's Voice Sample Based Covid Testing

Mumbai's Municipal Body is running a pilot AI-based project to detect COVID-19 infection in individuals.

Brihanmumbai Municipal Corporation (BMC) – the municipal body that runs the city administration in Mumbai, has recently initiated a study to assess the efficacy of AI-based test to detect COVID-19 infection in individuals (*BMC to conduct AI based Covid test, The Mint, 2020)*.

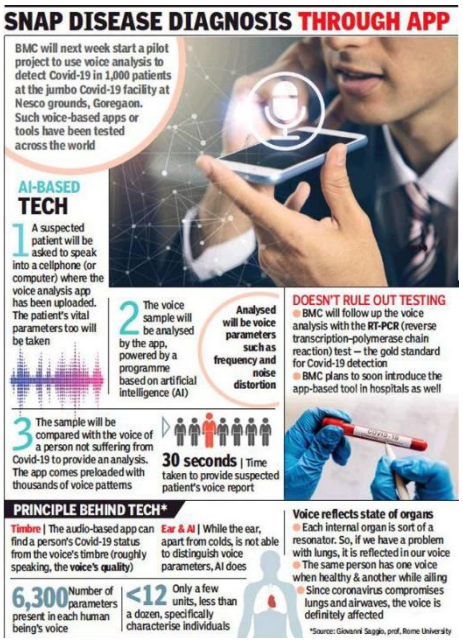


Exhibit 11: BMC to test for COVID-19 infection by using voice sample through AI-enabled smartphone app (Source: Economic Times)

This non-invasive test uses a smartphone app and provides results within 30 seconds.

The non-invasive test involves AI-based machines analyzing the sound waves in voice samples recorded by individuals. The patient will have to download an app on a smartphone and record a voice sample using that app. The app will then match this voice sample with the voice samples of millions of people who have earlier tested negative for COVID-19 that are already pre-loaded on the app. The result of this test will be generated within 30 seconds.

Voice samples detect adverse effect on lungs.

A human being's voice consists of about 6300 parameters. Whenever a person's lungs are affected by a disease, their voices are the first to get affected. However, in the initial stages, the change in voice is not perceptible to the human ear due to aural limitations. AI-based machines can quickly scan the 6300 parameters against those of the millions of voice samples already stored in the machine and detect changes in the voice sample being tested.

[11]Sensitivity is the ability of the test to correctly identify those with the disease (i.e., true positive rate)
[12]Specificity is the ability of the test to correctly identify those without the disease (i.e., true negative rate)

Positive results from the test will be cross verified with the help of RT-PCR tests

As part of the pilot project BMC will test voice samples of 1000 individuals. For all the patients whose voice sample-based test indicate the presence of COVID-19 infection, BMC will conduct nasal swab-based RT-PCR[13] test to confirm the COVID-19 positive diagnosis. If the results for this pilot project is promising, BMC will then roll out the test at scale to be available at hospitals and even at roadside testing facilities for the general populace (*Your smartphone can detect covid-19, DNA, 2020*).

Success of the pilot can address challenges associated with current testing procedures.

One of the most critical challenges that any public healthcare system faces in tackling any epidemic/pandemic is the lack of timely information about the extent of the spread of the disease in a given geographical area. For example, in the current COVID-19 pandemic testing has been a critical bottleneck across the globe. Issues related to testing are (a) inadequate testing kits, (b) inadequate laboratory infrastructure, (c) shortage of trained healthcare workers – for collection of samples and testing in laboratories, (d) high cost of tests, (e) risk to healthcare workers collecting samples, (f) long gap between sample collection and availability of result – during which period, an infected person infect others. Should the efficacy of the AI-based non-invasive test be established through the on-going study, all of these challenges can be addressed and testing of the larger population can be rapidly scaled up.

7.3 Case Study 3 – Narayana Health's Applications Across Hospital Functions

Narayana Health – using Data Analytics & AI to provide affordable, high-quality healthcare.

Narayana Health (NH), a leading hospital chain headquartered in Bangalore, operates 23 hospitals, 7 heart centers and 19 primary care facilities across the country. Dr Devi Shetty[14], well known cardiac surgeon and founder of NH, has articulated NH's mission as "providing accessible and affordable high-quality healthcare". To achieve this goal NH is leveraging the power of Data Analytics & AI to drive down costs and improve healthcare outcomes *(Narayana Health - using Data Analytics & AI to provide affordable, high quality healthcare, 2019*).

AI in hospital administration led to 70% reduction in man-hours for reporting.

In any hospital setup, administrative functions tend to add to layers in decision making and reviews, ultimately adding to costs which in turn add to the cost of healthcare borne by patients. NH has effectively used AI tools coupled with a centralized system leading to 70% reduction in man-hours spent on reporting and 50% reduction in time towards management reviews. These benefits have been passed on to patients in terms of lower healthcare costs.

Nursing staff efficiency increased by 15% within a month.

High attrition rate among nursing staff is a key challenge that all hospitals face as this creates significant disruption in the ability of any hospital to function smoothly. NH used data analytics to analyze granular details of nursing staff's workflow and the resultant insights enabled three hospitals within the NH network to report efficiency gains of 15% within a month.

Faster labs turn-around times – 95% of lab tests turned around in less than 2 hours.

A major friction point for patients in any testing procedure is that it requires at least two visits to the hospital to get a test report – once to give the sample and another visit to collect the report. NH used data analytics to compare the performance of different labs across the network to identify roadblocks as well as best practices. NH implemented changes in the clinical processes at one of the units which resulted in about 60% improvement in efficiency and close to 95% of lab tests being turned around in less than two hours. This meant that in many cases, the patient could consult a doctor, get the recommended tests done and get diagnosis done by the doctor on the same day.

AI-based product developed to distinguish normal and abnormal X-ray images.

The AI team at NH developed a product that can differentiate between normal and abnormal X-ray images. This helps doctors save time on routine screening functions and allows them to focus on more critical aspects that require their attention.

Better prediction of surgery costs – helps patients plan financial outlays better.

All the benefits derived from various processes where AI was effectively used eventually circles back to NH's core mission of providing affordable, high-quality healthcare. Before NH started using Data Analytics & AI, the quotes for surgery were updated periodically. Now, the systems are geared to estimate, in a very narrow band, the expected cost of a treatment, based on multi-year data of relevant procedures and costs.

8. Conclusion

AI is permeating many domains & healthcare is slated to be the biggest beneficiary.

AI, ML, Dl, NN – all these terms which were considered esoteric earlier and held "promise" have now moved on into the real-life applications which are making direct impact on the lives of millions of people across the world. Over the decade of the 2020s, AI is projected to make a very significant impact on many sectors and healthcare is likely to be one of the biggest, if not the biggest, beneficiary.

AI in healthcare has multiple applications.

As we have outlined in this paper, AI has multiple applications in healthcare – in various areas that constantly pushing the boundaries of where AI is permeating.

[13] Reverse Transcription Polymerase Chain Reaction (RT-PCR) is considered the gold standard for COVID-19 infection testing.

[14] Dr Devi Shetty has been awarded Padma Bhushan & Padma Shri, the third highest and fourth highest civilian awards respectively, by the Government of India for his contribution to the field of affordable healthcare.

Currently, the areas within healthcare where AI-based applications have already made meaning full impact can be divided into four broad categories – (a) administrative services, (b) screening & diagnosis, (c) treatment, nursing & monitoring, (d) drug discovery & medicine management.

India has under-invested in healthcare, but now plans to catch up.

India has traditionally under-invested in healthcare, both in terms of share of GDP and on per capita basis. India's spend as percentage of GDP on overall healthcare (3.6%) and public healthcare (1.3%) is way below those of comparable countries and WHO recommended norms. However, the Government of India recognizes this aspect and has identified healthcare, especially public healthcare, as a focus area – backed by higher financial outlays and forward-looking policies.

Public healthcare in India requires cost-effective solutions at scale – AI ideally suited.

As a developing economy, India has to balance the competing demands on its resources in terms of developing physical and social infrastructure to improve the lives of its citizens. Given the large needs of the public healthcare system and its population base, India has to find innovative solutions that are (a) cost-effective, (b) rapidly scalable, (c) high-quality, and (d) cognizant of India's shortage of doctors and other healthcare professionals. AI-led solutions are ideally suited to mitigate all these challenges and hence AI is likely to play a very important role in India's aspiration to scale up its healthcare system, especially public healthcare.

Pilots currently underway are showing promising results.

We have highlighted three cases studies in this paper where AI-led pilots have either already demonstrated significant benefits or exhibit significant promise. Google and Verily have combined with two eye hospitals in India to scale up screening for Diabetic Retinopathy. Mumbai's municipal body is currently running a pilot to test efficacy of AI-based voice sample screening for COVID-19 infection, using a smartphone app. Narayana Health, working towards its mission of providing affordable and high-quality healthcare, has employed AI and Data Analytics that have provided promising results in areas such as hospital administration, nursing, lab tests, radiology, and surgery costs.

AI-led healthcare solutions have the potential to power India's journey to an UMIC nation by 2030.

In conclusion, we are of the firm opinion that AI holds great promise for revolutionizing healthcare globally during the coming decade. India will have to focus on healthcare in general, and public healthcare in particular, to fulfill its aspiration of becoming an UMIC[15] by 2030. AI-led solutions will undoubtedly play a very important in powering this journey and improving the lives of India's citizens.

[15]Upper Middle-Income Country

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