THE ROLE OF DIGITAL HEALTH IN METABOLIC SYNDROME AND NCD PREVENTION IN INDIA: INSIGHTS FROM A LITERATURE REVIEW

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"The Role of Digital Health in Metabolic Syndrome and NCD Prevention: Insights from a Literature Review"

A thesis submitted in partial fulfilment of the requirement for the degree of Master of Science in International Health
by

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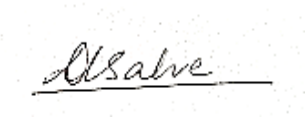
Signature: 

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Abstract

Introduction: Metabolic syndrome and non-communicable diseases (NCDs) are rapidly increasing in India, becoming an enormous public health problem. Although digital health interventions (DHIs) show promise, they are often met with a lack of trust due to non-standardized evaluation methods. This research aims to assess how effective, safe, and user-friendly DHIs are in preventing metabolic syndrome with its associated NCDs within India.

Methods: A literature search was carried out using databases like PubMed, Vrije University digital library, Scopus, etc as well as search engines like Google Scholar among others. The focus was on studies that evaluate DHIs for the prevention of NCDs in India.

Results: The study established that the success of wearable devices; mHealth applications; telemedicine; artificial intelligence etc., in controlling metabolic disorders and NCDs within India largely depends on their ease of use and user experience. However, there still exist some challenges, especially in rural settings where limited digital literacy coupled with infrastructure hinders the effectiveness and accessibility of e-health services. Language barrier together with the preference for regional languages over English also a contributed to the challenges. Even though Precision Public Health (PPH) holds potential it is limited by inadequate skilled manpower.

Discussion: In order to promote the adoption of DHI throughout India comprehensive preventive healthcare policies must be formulated while at the same time prioritizing prevention care. Also, there is a need to address data security and privacy issues as well as interoperability among different digital health systems. Such efforts if successful, would go a long way towards reducing the burden of NCDs upon Indian society thereby transforming its healthcare landscape for the better.

Keywords: metabolic syndrome, non-communicable diseases, preventive, digital health intervention, India

Word count: 11,956

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List Of Abbreviations:

ABDM- Ayushman Bharat Digital Mission

AI- Artificial Intelligence

BMI- Body Mass Index

CHANGE- Canadian Health Advanced by Nutrition and Graded Exercise

CRC- Colorectal Cancer

CVD- Cardiovascular Disease

DHI- Digital health intervention

eHealth- Electronic Health

EHR- Electronic Health Record

FHIR- Fast Healthcare Interoperable Resources

GO- Generalized Obesity

HIE- Health Information Exchange

HISs- Health Information Systems

HWCs- Health and Wellness Centers

ICMR- Indian Council of Medical Research

ICT- Information and Communication technology

ISO- International Organization for Standardization

LMICs- Low- and Middle-income countries

MARS- Mobile App Rating Scale

mHealth- Mobile Health

MoHFW - Ministry of Health and Family Welfare

NRHM- National Rural Health Mission

NCD- Non-communicable diseases

NDHM- National Digital Health Mission

NPCDCS - National Programme for Prevention and Control of Cancer, Diabetes, Cardiovascular Diseases & Stroke

PPH- Precision Public Health

T2DM- Type-2 Diabetes Mellitus

UN- United Nations

UX- User Experience

WHO- World Health Organization

Key Terms

Non-communicable diseases (NCDs): chronic illnesses resulting from a blend of behavioral, physiological, environmental, and genetic factors (Kaur et al., 2022).

Metabolic syndrome: a cluster of metabolic risk factors such as increased blood pressure, hyperlipidaemia/dyslipidaemia (increased levels of fat in the blood), hyperglycaemia (increased levels of glucose in the blood), and overweight/obesity, all of which trigger individuals to cardiovascular morbidity and mortality (Zimmet et al., 2005).

Digital health: Digital health is a blanket term covering electronic health (eHealth), mobile health (mHealth), and other innovative technologies such as big data, genomics, and artificial intelligence (WHO, 2019).

mHealth: the application of Information and Communications Technology in the promotion and improvement of health as well as health-related disciplines (WHO, 2019).

Interoperability: refers to different digital health systems and devices working together within the larger healthcare ecosystem (Mathew et al., 2019)

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Finally, I would like to dedicate this work to all those people who always encourage me to seek knowledge and truth.

"May this work serve as a beacon of positive change for humanity and our planet!"

Introduction

As a medical doctor, catering to the community, I have noticed the incidence of non-communicable diseases like hypertension and type-2 diabetes to be on the rise in my clinical practice, in India. The alarming point is that the majority of my patients are young adults, as compared to elderly patients. My practice is mostly about treating these diseases as a result of changing lifestyles occasioned by urbanization, sedentary lifestyles, and increased consumption of unhealthy foods.

Many NCDs are preventable when they are diagnosed early through routine health check-ups and simple lifestyle changes. However, once these diseases develop, they have a long course of treatment that is expensive too. I have come across many times where due to the enormous costs; patients stop their treatment only to suffer from complications and sometimes die premature deaths. This not only impacts their health but also makes the families face financial hardships.

Amid these challenges, I have found digital health tools to be highly effective in my practice. These tools have helped my patients monitor their health, receive personalized advice, and make better lifestyle choices, leading to improved outcomes in both the prevention and management of NCDs. My growing curiosity now lies in how these successful digital solutions can be adopted on a broader public health level, considering all the components of digital health interventions, as I also noticed the reluctance of the population to adopt these.

I am optimistic that, with the right strategies, digital health could revolutionize NCD management across India. Scaling these tools could empower millions to take control of their health, reduce the prevalence of NCDs, and alleviate the financial burden on families, ultimately leading to a healthier and more prosperous nation.

"THE ROLE OF DIGITAL HEALTH IN METABOLIC SYNDROME AND NCD PREVENTION IN INDIA: INSIGHTS FROM A LITERATURE REVIEW"

Chapter 1: Background

1.1 India: Geography, Demography and Population Overview

India is a colossal and varied country in South Asia that dominates much of the Indian subcontinent. According to estimates from the United Nations (UN), it has the highest population in the world, with 1,42 billion people at the end of April 2023. It comprises twenty-eight states and eight union territories. India is home to over 780 languages spoken across its territory; this makes it a linguistic mosaic. As recognized by the Constitution of India under the Eighth Schedule known as scheduled languages, there are twenty-two languages. Usually, each state of India has its official language reflecting the nations linguistic diversity. Hindi is the official language of the government, while business, education, and administration widely use English as an associate language.

Figure 1:Map of India

(Source-https://incredibleindiatour.net/states/)

1.2 Non-communicable diseases (NCDs) And Metabolic Syndrome

Non-communicable diseases (NCDs) are chronic illnesses resulting from a blend of behavioural, physiological, environmental, and genetic factors (Kaur et al., 2022). The metabolic syndrome is a cluster of metabolic risk factors such as increased blood pressure, hyperlipidaemia/dyslipidaemia (increased levels of fat in the blood), hyperglycaemia (increased levels of glucose in the blood), and overweight/obesity, all of which trigger individuals to cardiovascular morbidity and mortality (Zimmet et al., 2005). Metabolic syndrome and associated NCDs like type-2 diabetes mellitus (T2DM), hypertension, etc are chronic as compared to communicable diseases. These conditions are long-term and require continuous management to prevent complications and improve the quality of life. Managing the consequences of such diseases is costly in terms of money and less effective than prevention (Budreviciute et al., 2020). A study estimated that 80% of type-2 diabetes mellitus cases, up to 80% of premature heart disease and stroke, and 40% of all cancers could be prevented by effective preventive measures (Seyedsadjadi and Grant, 2020). This shows how important the adoption of preventive strategies could be in reducing the number of these debilitating disorders. In addition, prevention approaches are known to be cheaper compared to interventions initiated after a person has already contracted a disease (Schwappach et al., 2007). For example, disease-modifying therapies like lifestyle changes (exercise and dieting), are useful for averting and managing NCDs including diabetes mellitus and cardiovascular diseases (Reboredo-Rodríguez et al., 2018).

1.3 The burden of NCDs and Metabolic Syndrome

Every year approximately 41 million people die from noncommunicable diseases which accounts for 74% of the total deaths worldwide. 17 million people die below the age of 70 due to NCDs annually, almost ninety percent of these early fatalities take place in low- and middle-income nations (LMICs). Among all NCD-related deaths, 77% occur in LMICs (WHO, 2023). In India, NCDs are estimated to be responsible for 63% of all deaths (Behera and Pradhan, 2021). The major non-communicable diseases in India are cardiovascular disorders (CVD), type-2 diabetes mellitus, chronic respiratory conditions, and cancer (Chauhan et al., 2022; Kundu and Chakraborty, 2023; Chauhan et al., 2021). Since 2000, communicable diseases like HIV/AIDS and diarrheal diseases have halved the number of DALYs and conversely, diabetes has increased by over 80% in terms of DALYs between 2000 and 2019 (Global health estimates: Leading causes of DALYs, no date). NCDs are identified as the predominant cause of death, and there has been a major shift from communicable to non-communicable diseases in India (Arokiasamy, 2018; John et al., 2023; Mohan et al., 2019). This transition is largely driven by behavioural and metabolic risk factors. Behavioural risk factors include smoking, unhealthy diet, sedentary lifestyle, alcoholism, and often result in metabolic syndrome. The existence of metabolic syndrome has been linked with higher chances of cardiovascular diseases and type-2 diabetes mellitus (Mamatsashvili et al., 2018).

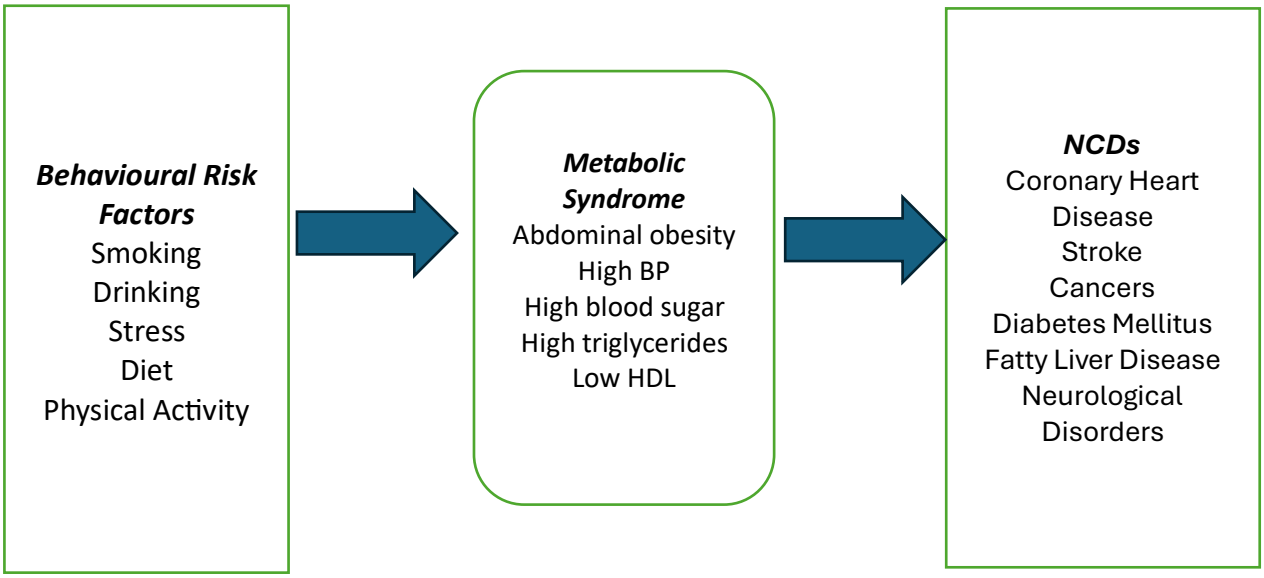

Figure 2:Figure 2: Metabolic syndrome and its risk factors & consequences.

(Mamatsashvili et al., 2018).

The metabolic syndrome including obesity, especially central obesity and insulin resistance resulting in the development of type-2 diabetes mellitus is a global health challenge, including in India. The levels of obesity and diabetes in India are very high with several studies showing an increasing trend over the years. In India, the prevalence of diabetes among adults aged 20 years old and above rose from 5.5% in 1990 to 7.7% in 2016 (Tandon et al., 2018). This growing trend was also shown by another Indian study which stated that there were about 77 million diabetes patients in 2019 with expectations of reaching around 134 million by the year 2045 (Pradeepa and Mohan., 2021). Owing to this, Indian research showed that there was a high prevalence of obesity measuring the total prevalence of generalized obesity (GO) to be 35.07%, and central obesity to 85.82% among individuals with newly onset type-2 diabetes mellitus hence emphasizing its association with multiple health challenges- like CVD (Singh et al., 2023).

The Madras Diabetes Research Foundation, working with the Indian Council of Medical Research (ICMR) and the Ministry of Health and Family Welfare (MoHFW), undertook a nationwide study across 28 Indian states and three union territories from 2008 to 2020 that looked at people aged 20 years and above. They reported finding that there are about 101 million diabetics in the country; additionally, they identified approximately 136 million individuals as pre-diabetes cases while another 315 million have been diagnosed with high blood pressure. Moreover, 254 million Indians were classified with general obesity based on their body mass index (BMI); and 351 million with abdominal obesity. The researchers also noticed hypercholesterolemia among 213 million people which will increase chances for heart attacks or strokes (Anjana et al, 2023).

Additionally treating NCDs, especially diabetes has become twice as expensive for households living in towns or cities (Mathur and Shah, 2011). According to Paul and Singh (2017), these findings challenge public health systems because of the double burden of diseases. Additionally, it has been seen that when people are affected by several NCDs together (multimorbidity), it increases medical help-seeking behaviour along with out-of-

pocket payment expenditure on treatment costs (Pati et al., 2014). Thus, managing such illnesses may have profound implications for money matters in terms of escalating health spending leading to catastrophic health expenditure events (Kastor and Mohanty, 2018). Moreover, beyond individual levels, the burden of these conditions can be devastating at the family level resulting in catastrophic effects in the form of excessive out-of-pocket payments and economic consequences (Karan et al., 2022).

1.4 Contributing Factors

Rapid urbanization and industrialization brought about by globalization have greatly transformed the way of living as well as health-risk behaviour among Indians leading to more cases of NCDs and metabolic syndrome like dyslipidaemia, obesity, hypertension, etc. (Alalageri, 2023). The socio-economic transition associated with globalization and urbanization has affected health risk behaviours further worsening the already high burden of NCDs in rural and urban areas across India (Shanmugam et al., 2018). In recent times there has been an increase in prevalence rates for chronic illnesses such as cardiovascular disease, cancer, etc specifically among city dwellers than any other group in society (Amballa, 2022). This is further revealed by a study done as part of the Indian Council of Medical Research–INdia DIABetes (ICMR–INDIAB) that urban residence, abdominal obesity, and hypertension were some of the factors associated with type-2 diabetes (Anjana et al., 2011).

1.5 Healthcare System

Furthermore, workforce distribution, infrastructure, technology integration, and equity in service provision are some of the challenges that the Indian healthcare system faces. The recent health sector reforms especially since the launch of the National Rural Health Mission (NRHM) in 2005 have been aimed at strengthening the public health system and improving the population-to-health worker ratio (Karan et al., 2021). Nonetheless, inequalities in accessing healthcare services still exist mainly in rural areas where there is limited availability of better-quality care (Kasthuri, 2018). Social, economic, and political factors in India affect both access to and quality of healthcare services provided in public hospitals as they present significant challenges (Bajpai, 2014). India also has a blend of private and public healthcare providers and healthcare accessibility, and affordability depend on the people's economic status (Carrasco, 2023).

Another considerable challenge remains of the low doctor-to-patient ratio which delays the diagnosis and treatment of NCDs. This includes but is not limited to rural areas where affordable government hospitals are underutilized, especially by vulnerable groups who are disadvantaged in accessibility due to their location or social status (Bhor, 2023). Lack of access to timely adequate healthcare can therefore fuel progression as well as push up costs incurred during illness periods for patients together with their families having them suffer more financially as the treatment is delayed.

Additionally, the health system is concentrated more on curative care rather than preventive care, and communicable diseases are the primary focal areas compared to non-communicable diseases (Elias et al., 2018). This has presented challenges in addressing various health needs of the populace since the demand varies. Private healthcare institutions in the current Indian setting exist to serve the affluent demographic, providing consultative, curative, and selected

primary healthcare services (Matlakala, 2024). This has been mainly attributed to perceived better quality and better facilities offered by these facilities hence increasing inequalities in health care provision between richer and poorer populations of the country. To address all these issues, comprehensive measures are needed.

1.6 Digital Health

Digital health, the fastest growing tech, can be found where technology is used to improve clinical practices and healthcare, to boost patient outcomes, and to promote well-being among the population in general. Digital health is on the rise and has been steadily growing in the last two decades. The World Health Organization (WHO) defines digital health as a blanket term covering electronic health (eHealth), mobile health (mHealth), and other innovative technologies such as big data, genomics, and artificial intelligence (WHO, 2019).

These technologies could be fundamental in addressing metabolic syndrome through the revamping of lifestyle changes, physical exercises, and healthy eating habits like the consumption of legumes which are well known for their high nutritional value and are known to have a positive impact on obesity and related conditions such as metabolic syndrome (Rebello et al.,2014).

Table 1: Digital health components and their uses

Digital Health Components	**Use**
Mobile health (mHealth)	The application of mobile devices especially handheld devices like mobile phones and tablets used for health-related purposes ranging from medication alarms, health promotion, etc
Telemedicine and Telehealth	Technologies that are employed in the delivery of healthcare services via information technology such as electronic communication and remote consultation.
Wearable Devices	Devices like fitness trackers, smartwatches, and any other device that a patient may wear to monitor their status, be it physical activity, blood pressure, heart rate, and so on.
Health Information Exchange (HIE)	The electronic transfer of health information from one healthcare organization to another.
Artificial Intelligence (AI)	AI can be defined as the set of procedures or processes that employ the use of artificial intelligent systems to solve problems that require human intelligence.

Information & Communication Technology (ICT)	ICT means the utilization of technology to transmit, process, and store information. In the health sector, ICT is useful in the way it can facilitate communication, increase access to care, and involve patients.
Health Information Systems (HISs)	Health Information Systems (HISs) are all those systems developed to support, process, store, analyze, and retrieve healthcare information. HIS facilitates proper decisions that lead to better delivery and outcome of healthcare.
Electronic Health Record (EHR)	EHR is comprehensive medical records of a patient that are electronic and can be accessed by other authorized caregivers. It enhances patient care outcomes, decreases medical errors, and fosters patient care coordination.
Health Data Analytics	Health data analytics refers to the use of data as well as analytical techniques in enhancing health and healthcare.

(WHO, 2019)

Digital health solutions can enhance the prevention of metabolic syndrome in India by providing personalized health interventions, fostering community health programs, and supporting research and education on risk factors and prevention methods. A study done in Korea showed that digital platforms with gamification have proven successful in educating the population about metabolic syndrome, obesity, and type-2 diabetes mellitus to promote healthy behaviour and preventive measures (Shin, 2019).

Furthermore, a survey was done to assess the preparedness of health systems to adopt mHealth strategies in LMICs to tackle NCDs, which showed the use of digital health strategies helped address many healthcare problems in LMICs, one of these being cardiovascular risk reduction. The research unveiled that the decrease in risk for heart diseases using mHealth is made possible through continuous monitoring of health, educating patients, encouraging changes in behaviour, making care easily accessible as well as involving communities in health management. (Feroz et al., 2018).

Digital interventions can relate to a wider range of the population offering personalized care and improving the health status of people suffering from NCDs (Hossain et al., 2019). Digital health interventions can be a vital tool in encouraging healthy behaviours, facilitating early diagnosis, and offering continuous support in the management of diseases, especially in high-risk populations (Larbi et al., 2020).

Additionally, the shift between underweight and overweight as well as obese individuals in India points to specific approaches targeting the rising prevalence of chronic diseases linked to obesity (Venkatrao et al., 2020). Digital health platforms can provide scalable weight management and lifestyle changes so that prevention and control of these diseases can be easily conducted (Summers and Curtis, 2020). Among the various problems faced by the health system in achieving optimal and universal coverage, digital health technologies such

as electronic decision support tools, mHealth, telemonitoring, and remote monitoring can help solve this problem (Tromp et al., 2022). Metabolic disorders and NCDs can be prevented at a low cost and on a large scale by using lifestyle interventions via mobile applications and conversational agents (Castro, 2022). The new digital India has given rise to digital health initiatives like government-led digitalization, Ayushman Bharat Digital Mission (ABDM), and in the private sector, digital ventures like digital health start-ups, tele-consultations, etc.

1.7 Ayushman Bharat Digital Mission (ABDM)

Ayushman Bharat Digital Mission (ABDM) is one of the flagship programs initiated by the Government of India that intends to transform its allied healthcare sector by integrating digital solutions. ABDM includes many components that are meant to transform the healthcare sector through digital innovations. The program, under this mission, seeks to provide universal primary healthcare services to the population through Health and Wellness Centres (HWCs) (Lahariya, 2018). These centres are important for improving access to primary, secondary, and tertiary care health services across the country because they ensure the availability of these services as well as affordability.

Figure 3: Ayushman Bharat Digital Mission (ABDM)

(https://abdm.gov.in:8081/uploads/ABDM_Potser)

Another initiative included in this mission is the e-Sanjeevani platform which acts as a national telemedicine service (Parmar et al., 2023). This platform helps increase the reach of health care by enabling remote consultations and other medical interventions thereby making it possible for people living across different parts of India to get necessary treatment without having them travel long distances or visit hospitals physically. Additionally, there is also a need for the creation of an integrated digital health ecosystem in India by building digital highways so that all stakeholders within the healthcare system can seamlessly communicate (Samudyatha et al., 2023).

Figure 4:eSanjeevani App

https://abdm.gov.in:8081/uploads/ABDM_Potser)

The Ayushman Bharat Digital Mission aligns closely with the National Digital Health Mission (NDHM) vision in India (Saksena et al., 2021). NDHM aims at creating a federated national digital health exchange where all digitized data generated by healthcare providers can be securely shared and accessed through electronic personal health records thus allowing citizens to become more engaged with their care while also enabling providers to deliver better coordinated services. This interoperable framework will promote equitable digitization of healthcare across India (Sharma et al., 2023).

Apart from focusing on general digital health infrastructure, the ABDM also addresses some specific healthcare challenges such as noncommunicable diseases (Rana, 2024). Through the adoption of digital health records systems within its design, it hopes to provide comprehensive solutions for the management and prevention of NCDs. This is expected to bridge the gap between these two sectors thereby creating a better understanding among them which may lead to improved health outcomes for individuals in India (Vikraman et al., 2022).

Furthermore, ABDM plays a crucial role in achieving Universal Health Coverage by 2030 alongside other key healthcare initiatives in the country (Sudha, 2023). By integrating with programs like the Ayushman Bharat scheme and National Health Policy; the mission intends to strengthen service delivery as well as widen access to quality care across all citizens. The focus on digital inclusion and technology utilization underscores this mission's commitment to enhancing health system performance while at the same time addressing disparities in well-being (Vasanthan, 2024).

Chapter 2: Problem Statement, Objective, and Justification

2.1 Problem Statement and Justification

In India, the growth of health solutions for dealing with NCDs is significantly impeded by the lack of standardized evaluation methods which leads to distrust among people towards digital health solutions. Due to the lack of faith in these interventions, their effectiveness and acceptance may be hampered (Haasteren et al., 2018). Although some successful digital health initiatives like ABDM have made strides in India, trust and acceptance continue to pose challenges (Gopal and Jat, 2024).

Digital health solutions can revolutionize healthcare in India by providing affordable and accessible services, especially in remote areas where access to conventional healthcare is limited (Makal, 2023). This aim of establishing an integrated digital health infrastructure through the ABDM represents a move towards using digital technologies to solve the country's healthcare problems (Samudyatha et al., 2023). However, it should be noted that for such programs aimed at incorporating technology into medical practice within hospitals/ clinics across different states or regions within India, they need to first consider provider-patient relationships before being fully integrated into existing systems (Panda, 2023).

Digital health interventions are one of many tools to use/consider while trying to reduce the burden of NCDs in India. These can help reduce deaths related to NCDs by improving prevention, diagnosis, and treatment through leveraging technological tools such as mobile phones or computers (Hossain et al., 2019). Nevertheless, sustainability and scalability issues cannot be overlooked when implementing any kind of program related specifically to digitalization within the country unless we address all forms concerning trust, and interoperability integration issues (Singh et al., 2021)

To address this gap there is a need for a comprehensive overview of the evidence regarding the status and results of DHIs following standard evaluation criteria. This will help to examine various digital health products for effectiveness, reliability, usability features, affordability, and data safety, thus ensuring that only innovative high-quality solutions get recognized or accepted into practice. Such measures will help increase confidence in clinicians and their patients; the private sector, and government agencies to analyse effectiveness and identify areas for improvement while also inspiring developers to make better more robust technologies. Furthermore, assists regulators by providing evidence-based guidelines on approval processes for new digital health tools thereby safeguarding public welfare within India.

2.2 General Objective

To analyse the efficiency, safety, and ease of use, of existing Digital health interventions in preventing metabolic syndrome and related non-communicable diseases in India.

2.3 Specific Objectives

1) To analyse the **technical validation like reliability, interoperability, and security** of DHIs in preventing metabolic disorders and related NCDs.
2) To evaluate the **clinical effectiveness** of digital health intervention in preventing metabolic syndrome, and related NCDs.
3) To assess the **usability** of digital health solutions in preventing metabolic syndrome and related NCDs, focusing on user experience, and integration of DHI into user's daily lives.
4) To evaluate the **cost-effectiveness** of implementing digital health interventions for preventing metabolic syndrome and related NCDs, considering factors such as affordability and long-term economic benefits for individuals and healthcare systems.
5) To provide **recommendations** to stakeholders (policymakers, healthcare providers, private sector, and government agencies) based on evidence and insights gained from studying the research questions of objectives 1–4.

Chapter 3: Methodology

Scope of the study:

The main area of the study is on the prevention and reduction aspect of metabolic syndrome and related NCDs through digital health interventions and not on therapeutic management. Regarding prevention, the study focuses on what can prevent or reduce metabolic syndrome and its complications from the onset and development. This differentiation highlights the need for preventive actions such as lifestyle enhancements, provision of healthcare services, and empowering environments to support general well-being. According to this paradigm shift, the essence of my research is to play a vital role in the improvement of public health policies including digital health that aim to reduce the prevalence and impact of NCDs in different populations in India. The DHIs that will be studied are wearables & biosensors, mHealth, telemedicine along with AI and ICT (information and communication technology). The selection of DHIs was based on their ability to tackle the unique challenges associated with metabolic syndrome and non-communicable diseases in India. Some challenges include inadequate healthcare access, demand for personalized scalable solutions, continuous patient monitoring, and engagement. These technological interventions provide cheap, accessible, and culturally relevant solutions that can be customized to fit the various needs of different populations within India.

A literature review was conducted to find, evaluate, and put together related research papers on the role of digital health interventions in preventing metabolic syndrome and non-communicable diseases (NCDs) in India. The main databases that were used included Vrije University digital library, PubMed, Scopus, Web of Science, search engines like PubMed, Google Scholar, and grey literature. The articles published from 2014 up to 2024 were considered during the initial search to ensure that recent studies are included in this review. The snowballing technique, a search strategy employed to locate other related studies based on already found papers' bibliographies or through papers citing the original studies was utilized to get all-inclusive information from various sources. To carry out the search, a combination of keywords and Medical Subject Headings (MeSH) terms was used. The search was refined by using boolean operators such as OR and AND between terms. The keywords are listed in Annexure 1.

Inclusion Criteria:

Primarily, studies carried out in India or had a notable Indian population concentration were included in the *Result* section unless there were no studies found on the subject, especially in studying *specific objective 1*. For the Discussion section, studies from developed countries were included to study the best practices. Articles published in English. Research papers, review articles, systematic reviews, and meta-analyses.

Exclusion Criteria:

Articles not published in English. The studies do not address digital health interventions. The articles do not focus on the prevention of metabolic syndrome or related NCDs. The editorials, commentaries, letters to the editor, and conference abstracts.

Ethical Considerations:

Ethical approval was not required for this literature review as it did not include direct interaction with human subjects or collection of primary data. However, ethical guidelines were followed for thorough reviews during the process ensuring transparency, accuracy, and respect for intellectual property rights by appropriately citing all included studies.

Limitations:

This analysis may suffer as it only considered the literature in the English language. It also has limitations in terms of generalizability due to the diversity in study designs, populations, and outcomes. Nevertheless, this review presents a global look at what is known so far about digital health interventions for preventing metabolic syndrome and NCDs in India.
By ensuring that only the most relevant sources are taken into consideration during the study selection process, this method guarantees a thorough examination of literature related to the impacts of digital health intervention programs on metabolic syndrome as well as non-communicable diseases in India.

3.1 Analytical Framework of Healthcare: Digital health scorecard framework:

Digital health solutions are extending their reach at a fast rate, but because of the unstandardized evaluation procedures, patients, clinicians, and payers continue to doubt their efficacy. Mathew et al. (2019) suggested a validation process that is open and objective to enable stakeholders to differentiate between genuine and value-adding digital health products. The Digital Health Scorecard is a framework for evaluating digital health solutions in a transparent and standardized way. The intended purpose of this tool is to solve the problems that currently exist within the digital health market, where it has become increasingly difficult for stakeholders to pinpoint high-quality products due to the rapid growth of new technologies. The digital health scorecard measures four domains when looking at these services: technical, clinical, usability, and cost. *Technical* validation checks the solution's accuracy, dependability, security, and ability to work with other systems. *Clinical* validation, on the other hand, looks into whether it improves certain health outcomes based on guidelines based on evidence. *Usability* determines whether a product fits into everyday life while assessing user experience (UX) engagement and workflow integration. *Cost* assessment looks at product cost, cost-effectiveness, and scalability.

A requirements-driven development approach assures that digital health products are built around well-defined needs. Pre-market and post-market independent evaluation by authorized entities gives impartial insight into solutions' performance across various stages of their lifecycle. Patients, clinicians, payers, and regulators are among the stakeholders involved, ensuring a unified framework that fosters trust in digital technologies. This allows for

informed decision-making regarding the most suitable interventions for specific purposes among different user groups, including but not limited to individuals with chronic diseases who require ongoing support outside traditional healthcare settings like hospitals, clinics, etc.

I have used this framework to define my objectives. This framework aids in assessing Digital Health Interventions (DHIs) related to *Technical* factors, that help measure the health parameters like blood glucose levels or physical activities, which are crucial for assessing risk factors and accurately recorded. *Clinical* appropriateness assesses whether these enhancements are effective in achieving health outcomes, as well as in following standard clinical protocols. The focus of *Usability* lies in the effective integration of these solutions into users' lives, which ensures their continuous use and fosters the behavioural changes necessary for long-term prevention. I have changed the last domain of *Cost* from the purchase price of the product and cost-effectiveness to the cost-effectiveness as a long-term economic benefit for people and healthcare systems of different DHIs in preventing metabolic disorders and related NCDs. I will be reviewing evidence and literature, using the dimensions of the framework to identify the relevant information and present it in a standardized way. This systematic approach will allow me to identify gaps in terms of what is published about digital health interventions.

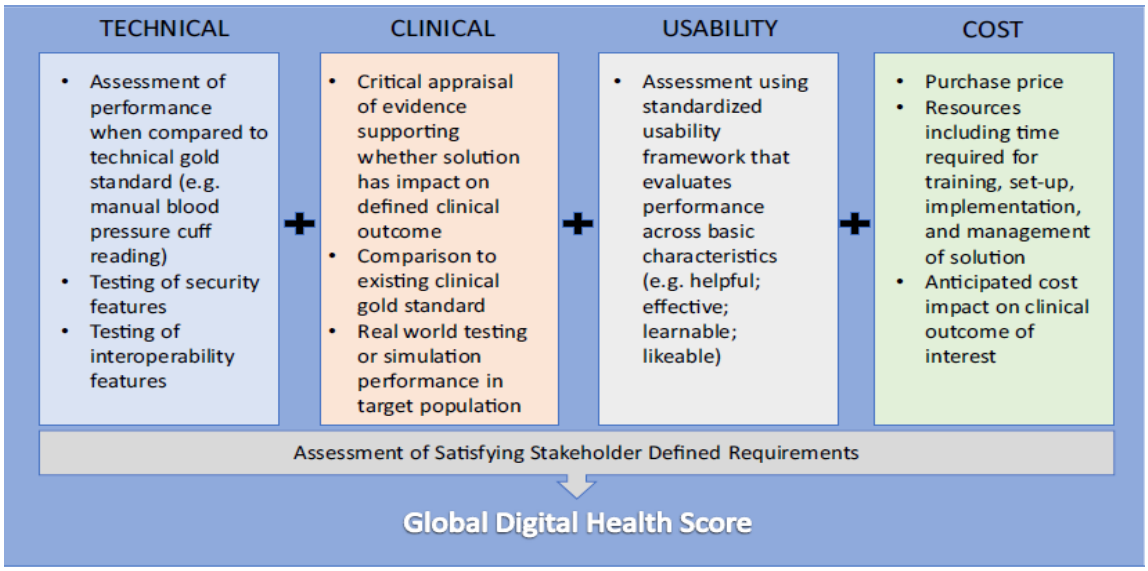

Figure 5:Digital health scorecard

(Mathew et al, 2019)

Chapter 4: Results

4.1 Technical Validation- Reliability, Interoperability & Security

When analysing DHIs like mHealth, telemedicine, wearables, and AI in the prevention of metabolic disorders and associated NCDs, things that are important to consider are technicality, interoperability, and security.

Technicality is about how well a digital health solution performs its intended functions. This includes the accuracy and reliability of the collected data by this app or system. For instance, a blood glucose monitoring application should have high precision i.e., it should give consistent readings to be useful at all times. It's important to ensure technical robustness because inaccurate data can lead to wrong diagnoses which may cause harm instead of good for patients who need treatment (Mathew et al., 2019).

Interoperability refers to different digital health systems and devices working together within the larger healthcare ecosystem. In simple terms, one should be able to share information from one tool with another easily, for example, electronic health records (EHRs) used by providers could accept input from fitness trackers worn on patients' wrists that monitor their daily activity levels alongside heart rate changes during workouts or rest periods. Thus, ensuring comprehensive care delivery through integration across platforms where necessary without any barriers preventing such exchange from happening due to lack of compatibility between them otherwise valuable resources will remain isolated inside individual devices/apps limiting usefulness towards managing/preventing NCDs over time (Mathew et al., 2019).

Data security provides a protective shield to health information from disclosure to the public, violation, or unauthorized use. When considering digital health solutions, data security an important component of technical validation is one of the main areas that need to be assessed about such technologies. This is because patient confidentiality is a key component within any successful digital health solution, as patient data can often be interfaced back with broader EHR systems. The modern application must provide a high level of data security protection, including encryption of patient information from simple vital signs to critical health details. If data is not protected there is always a possibility that sensitive information will be exposed, and this may cause harm to the patients and eventually erode the credibility of the DHIs. Hence, the protection of data is one of the core components that run the fabric for the secure and efficient use of most of the technologies in the health sector (Mathew et al., 2019).

The number of digital health apps used in India has increased dramatically because of the National Digital Health Mission initiative which was launched under the "Digital India" program to improve healthcare accessibility and efficiency (Jain, 2023; Mantri, 2024). These applications include personalized care pathways, support for chronic disease, and mental health management among other features (Lehne et al., 2019; Larbi et al., 2020; Boonstra et al., 2018). Concerning the use of digital health as an integrated model of care, there are key issues that need to be addressed, including but not limited to interoperability, security, and privacy (Pant et al., 2022).

In addition, DHIs have been instrumental in responding to public health emergencies like COVID-19 by showing their potential to manage diseases (Lehne et al., 2019; Mantri, 2024). Nevertheless, legal and ethical considerations, data privacy, reliability, and cost are some challenges that hinder the seamless integration and utilization of these applications (Aljedaani and Babar, 2021; Claudio, 2024). According to a study, security vulnerabilities due to poor practices or a lack of developer knowledge pose significant risks to user data (Aljedaani and Babar, 2021).

There is a lack of literature evaluating the technicality and interoperability of DHIs, especially in the Indian context. Since there isn't a study that directly asks if all health apps and other DHIs go through a quality check before they are sold in India, and if they do, what regulatory body is in charge of it, especially in the private sector. Researchers have used the Mobile App Rating Scale (MARS) to assess the quality of smartphone applications for various health conditions, demonstrating a standardization in app quality evaluation (Davalbhakta et al., 2020; Portenhauser et al., 2021). Despite the lack of specific focus on the Indian market in these studies, tools such as MARS underscore the necessity of systematic quality assessment in app development and deployment. MARS has shown excellent internal consistency and reliability, besides being useful as a reliable method for classifying and assessing the quality of mobile health apps (Stoyanov et al., 2015). Therefore, the use of standardized criteria to assess the reliability and effectiveness of mHealth applications, despite the need for further research in this area. Such structured approaches to evaluating app performance may help bridge the gap between what we know about their efficacy currently and tools like MARS (Kao & Liebovitz, 2017).

According to a consensus report by the European Association for the Study of Diabetes (EASD) and the American Diabetes Association (ADA), the accuracy, reliability, security, and interoperability of digital health apps for diabetes are of great concern (Fleming et al., 2020). Most of these applications do not provide enough clinical evidence that they can be used in treating diabetes. Concerning this matter, various studies have indicated that many applications share user-sensitive information with third parties without their consent, which shows a lack of data protection measures. In addition to this limitation, interoperability is another challenge since most of these applications do not communicate effectively with other health systems or devices thereby limiting comprehensive use in diabetic care (Fleming et al., 2020).

Interoperability is one key factor often highlighted during the integration or data exchange process of any given health app into existing systems, but recent studies have concentrated on this aspect more than before. To demonstrate the reliability and quality of well-being applications, national or global standards-setting organizations such as the International Organization for Standardization (ISO) need to establish guidelines for health/wellbeing apps (Willemsen et al., 2023). To make it easier for healthcare IT systems to share information with each other, the *Fast Healthcare Interoperable Resources (FHIR)* framework and other similar projects helped make health apps work together (Frid et al., 2022). Relevant authorities, such as the government, must take the necessary steps to address interoperability challenges in Indian digital health systems. They can provide leadership and collaborate with other stakeholders in the country's healthcare delivery system (Lehne et al., 2019; Shear et al., 2023). According to Ndlovu et al. (2023), achieving the exchange of information between different medical records requires the establishment of common methods for patient data collection. Therefore, it is crucial to establish technical standards to streamline this process.

Concerns about data privacy and security are extremely relevant, especially when it comes to personal health information protection and the possibility of data misuse (Jain, 2023). In India, biometric identification changes access to health care by simplifying the process of identification hence making it efficient and reducing the time beneficiaries wait. This enables the directed delivery of services so that medical resources can reach those who need them most especially through programmes like the Rashtriya Swasthya Bima Yojana (RSBY). However, this dependence on biometrics raises questions about conditional entry which might exclude marginalized populations that lack the necessary technology or infrastructure. There are also concerns about privacy and security concerning data since people may not want to participate in digital healthcare systems due to fear of biometric misuse. Biometrically identifying people has the potential of giving them power over their rights but at the same time, it can be used for abuses thereby necessitating protection measures for these two categories whose safety nets should not be compromised (Dahdah et al., 2023). To ensure that sensitive health information is protected, and users trust the system more, there should be strict enforcement mechanisms put in place coupled with strong data privacy regulations (Jain, 2023).

Also, the digitalization of health interventions in India is not simple as it brings challenges related to the security of information and privacy where a digital divide in terms of health care exists (Hossain et al., 2020). For patient confidentiality and trust in digital healthcare undertakings, protection of health data is a must (Velthoven & Cordón, 2019). Furthermore, sharing health data through Indian laws such as the Data Protection Act should be done to foster growth within the sector itself nationally (Venkataramanan et al., 2022).

The above analysis shows that it is crucial to have high-quality and effective DHIs to ensure to avoid incorrect diagnoses from happening, however, the systematic review of these solutions in the context of the Indian market remained largely unaddressed. Functionality such as interoperability which is influential when it comes to linking various aspects of digital health is still an issue since many applications are still unable to share information with the existing health care systems. Privacy is also an issue in the matter of data protection regarding confidentiality and other forms of unauthorized disclosure especially with the rise in the use of biometric systems. The gap pertains to the lack of extensive studies about technical assessment and compatibility, no universal guidelines for app evaluation, and insufficient focus on data protection, particularly the possibility of social exclusion experienced by minority groups from the opportunities offered by digital health solutions.

4.2 Clinical Effectiveness of Digital Health Intervention

The clinical domain evaluates the effectiveness of DHIs in improving the health of the population. This entails examining clinical research and data to determine to what extent the interventions align with the medical protocols and best practices concerning the health condition (Mathew et al., 2019).

In India, wearable devices and biosensors are considered potential tools for preventing and managing metabolic disorders and non-communicable diseases such as type-2 diabetes mellitus, hypertension, and lifestyle diseases. These can transform healthcare through continuous monitoring of physical activity, and vital signs among other health parameters (Chakrabarti et al., 2022). Wrist-worn wearables have been useful in diagnosing various

conditions including diabetes thus, underlining the need for early detection and intervention (Chakrabarti et al., 2022). Also, at the community level within India mHealth interventions were found effective in reducing physiological parameters like blood pressure (129.9 mmHg to 128.6 mmHg), fasting blood glucose (98.9 mg/dL to 97.5 mg/dL), and body mass index (BMI, 23.8 kg/m^2 to 23.7 kg/m^2) not only in promoting healthy behaviours but also in modifying behavioural risk factors associated with non-communicable diseases, hence indicating that mobile technologies could be used to drive positive changes towards healthier living (Sharma et al., 2017). In addition, a study argues that leveraging technology such as smartwatches could help detect them while still manageable even before signs appear thus saving many lives in the process despite the cost associated with treatment being very high and sometimes impossible (Nadhamuni et al., 2020)

Digital health interventions have become a powerful tool to support patients and healthcare systems with the increasing prevalence and economic burden of NCDs worldwide (Jakob et al., 2022). Positive results have been achieved by combining mobile health technologies and telemedicine in terms of chronic disease management, efficiency of the health system, and access to healthcare among underserved populations (Beratarrechea et al., 2014). Some studies indicate that mHealth interventions have helped reduce morbidity and mortality rates by reducing HbA1c from 7.96% to 6.8% and changes in behaviours leading to better patient satisfaction levels and overall quality of life-related to health status (Beratarrechea et al., 2014).

The use of mHealth together with telemedicine has led to improved adherence rates among patients following treatment regimens which has consequently resulted in better clinical outcomes thus empowering individuals living with long-term illnesses such as diabetes mellitus to self-manage their conditions effectively (Dsouza et al., 2022). There is evidence from different research done especially in low-income settings like those found within middle-income countries including India which indicates that self-management applications can indeed support people living with type-2 diabetes mellitus to manage their condition better leading to improved health outcomes through enhanced treatment compliance (Dsouza et al., 2022).

In India, healthcare delivery is increasingly seen as a sector that could be transformed by AI. Customer service improvement and better experience in health care are among the things being sought through AI technologies under initiatives such as the Ayushman Bharat Health Protection Scheme (Rodriguez et al., 2020). Furthermore, machine learning methods incorporated into existing therapeutic measures have shown promise when it comes to managing childhood obesity through systems based on artificial intelligence that enhance prevention efforts alongside treatment options already available in this area (Alghalyini, 2023). Programs aimed at prevention should adopt AI since they help make them more effective while at the same time reducing costs thereby making such interventions easily accessible and scalable (Rao et al., 2022).

The above results reflect those smartwatches, biosensors, and other digital health tools to facilitate constant tracking of health status, prompt identification of disease signs, and timely treatment that can enhance people's well-being and decrease medical expenditures. At the community level, the mHealth interventions have shown positive impacts on the behavioural and physiological determinants of health in the Indian context and the merging of mHealth with telemedicine has been found to improve chronic illness management and treatment compliance and the subsequent clinical outcomes, especially among the disadvantaged

population groups. Furthermore, AI is gradually being seen as the need to reshape healthcare in India through better customer relations, facilities, treatments, and preventions such as prevention of childhood obesity. Nevertheless, there are some limitations to knowledge regarding the application of such technologies in low-income contexts such as the longitudinal cost per patient of current AI and wearables, and how these forms of intervention might fit into the Indian healthcare system for the most efficiency.

4.3 Usability of Digital Health Solutions

Usability can be defined as the extent to which these digital tools are user-friendly or usable by people in their daily life practices. It is about ensuring that the applications, wearables, and other digital health solutions are easy to use for the majority of users, especially the low-tech population. It's critical because even a highly evidenced-based pragmatic digital health tool will be ineffective if people experience challenges or dissatisfaction in engagement (Mathew et al., 2019)

In India, usability and user experience are key aspects of DHIs like wearables, mHealth, telemedicine, AI, HIE, and ICT for the prevention of metabolic disorders and non-communicable diseases. It has been proven by research that mHealth applications can help patients as well as healthcare systems manage chronic diseases like diabetes mellitus and cardiovascular diseases (Jakob et al., 2022). More specifically, wearable biosensors can provide useful information for personalized interventions and monitoring in India where nutrition transition, excessive gestational weight gain as well as unique body composition features are some of the challenges facing NCD prevention (Misra et al., 2011; Kanneganti et al., 2019; Kumari, 2013). To integrate wearables and mobile health applications successfully into daily routines, constraints need to be addressed, and achieving user acceptance is vital for these technologies (Moorthy et al., 2024).

A study was conducted to examine the usefulness of the One Health app, a mobile application designed for managing hypertension and type 2 diabetes mellitus (T2DM) in Central India. During the six-month study, this research aimed at testing the practicability as well as the influence of this program. The main purpose of the study was to find out how effectively can self-care for chronic conditions be enhanced through the One Health application that enables patients to record their health information such as blood pressure levels and blood sugar levels. Various health indicators were logged by participants using this app. Data entry frequency, user involvement, and changes in health outcomes were measured during the study. The study reported, there were significant decreases in average diastolic BP (0.60 mmHg) and HbA1c (0.657 units). Hypertension was controlled in 53% while glycemic control occurred in 34%. This application received positive feedback with continuous engagement attributed to high retention rates and ease of use among users who also mentioned that it helped them monitor their well-being (Aviraj et al., 2024).

Usefulness is an important component in any successful telemedicine service which must be accepted by its users. ISO defines usability as the extent to which a system can be used to achieve specified goals with effectiveness, efficiency, and satisfaction (Aminoff et al., 2021). Also, without satisfaction or acceptance from users, no adoption or efficacy will be achieved

when it comes to this type of care provision therefore, these two factors cannot be overemphasized vis-a-vis telemedicine services success (Khairat et al., 2023).

In India where cases of non-communicable diseases continue rising steadily year after year, there has been an ongoing assessment of how usable mHealth applications can be for managing conditions like type 2 diabetes mellitus among others (Goswami et al., 2022). Therefore, making sure that all these programs are designed keeping simplicity at their core while still being more customer friendly is very important since it leads not only to betterment customer satisfaction but also portability so that many people may benefit from using these devices regardless of their geographical location within India (Gupta et al., 2021). Another thing worth noting about its usefulness is that it helps improve health literacy among vulnerable individuals such as hypertensives living in rural areas who might lack access to proper medical advice due to a lack of awareness or knowledge on what exactly should be done when faced with such conditions (Garner et al., 2020).

Furthering, these technology's utility, India being a geographically varied country can take advantage of the integration of wearable biosensors into telemedicine platforms that allow remote monitoring (Lukas et al., 2020). Moreover, the existing e-health framework in India has problems with accessibility as well as quality of services which is worse, particularly for rural areas (Goyal et al., 2022). However, this will not work unless we improve our e-health infrastructure through investing more resources into rural healthcare facilities and technology thus ensuring equitable access to quality healthcare services (Goyal et al., 2022).

Digital literacy remains a significant challenge for the country, especially in rural areas where access to healthcare information and services is limited (Nedungadi et al., 2018). The COVID-19 pandemic has underlined the significance of digital health literacy as people have to effectively navigate quickly changing health information and misinformation (Patil et al., 2021). With a high burden of NCDs contributing to substantial morbidity and mortality, countries like India must improve digital health literacy so individuals can make informed choices about their well-being (Hossain et al., 2019).

The major obstacle to improving digital health literacy in India is inadequate infrastructure and resources for supporting digital interventions for NCD prevention (Hossain et al., 2019). Most healthcare personnel report high levels of digital literacy which indicates that there might be a difference between healthcare providers' knowledge/skills on this matter compared to those within the general population (Kuek & Hakkennes, 2019). In addition, there exists a huge barrier posed by the digital divide against the enhancement of such literacies among vulnerable groups within India itself (Spaulding,2024). Precision Public Health (PPH) as an emerging approach that relies on electronic medical records for effective prevention against non-communicable diseases has shown great potential (Davidson et al., 2022). However, the lack of skilled personnel especially specialists who can manage NCDs poses big problems in India (Karan et al., 2023).

Two recent studies by Deb et al. (2018) and Chauhan et al. (2018) bring out the issues of language in the implementation of mHealth technologies in India. As noted by Deb et al. (2018), in low-resource settings, languages, cost, and unfamiliarity act as barriers to the implementation of mental health apps. Chauhan et al. (2018) pointed out that in India, there is a greater inclination toward the regional language, Hindi eclipsing English, which supports the need to include multiple language interfaces to improve the usability of apps and their utility in the population.

The result shows these technologies can assist in evaluating chronic disease management, though, it requires efficient management of user constraints where several patients from developing countries, especially from rural settings hardly have access to the internet, personal computers, or smartphones. A case of One Health app indicates improved health status and user satisfaction evidencing the possibilities of superior mHealth. However, issues such as language barriers with Hindi preferred to English are observed contributing to the necessity of multi-language interfaces to improve usability. Moreover, the results also identify other issues such as digital health literacy, infrastructure, and specialized workers to enhance the effects of DHIs in India.

4.4 Cost-Effectiveness of Implementing Digital Health Interventions

The assessment of the cost-effectiveness of digital health interventions in preventing NCDs determines if a digital health solution can deliver desired health outcomes like reducing NCD incidents cost-effectively vis-à-vis conventional measures or alternatives through cost-effectiveness analysis. This is critical in healthcare where decision-makers must utilize limited resources prudently towards interventions offering maximum health gains because many times there are not enough funds available globally for all needs within this sector. Hence, it will be evaluated whether DHIs work from both clinical effectiveness and economic feasibility points by looking at their cost-effectiveness; hence these will be more likely adopted and scaled up.

For a cost-effective trial evaluating wearable devices and biosensors as preventions in metabolic syndrome and NCDs in India, factors such as affordability, scalability, and individual and societal long-term economic gains, need to be kept in mind. Personalized health tracking, early identification of health problems, and promotion of preventive health behaviour change among others will lead to better health outcomes hence reducing healthcare expenses (Alouki et al., 2016). India could benefit from low-cost wearable biosensor technology that employs screen-printing methods. These can be embedded into wearables for people to monitor their parameters on a real-time basis (Yáñez-Sedeño et al., 2020).

Moreover, lifestyle interventions involving wearable devices and biosensors have important economic benefits concerning lifetime costs both at an individual level and for healthcare systems operating within India. By encouraging healthy eating habits including regular physical activity these technologies can help control some metabolic disorders thereby reducing the demand placed on healthcare resources which leads to improved population health (Alouki et al., 2016). In this regard, for instance, in diabetes, a common metabolic disorder in India lifestyle interventions aided by wearable devices are cost-effective approaches to preventing progression. The study showed that people who used wearable devices experienced significant enhancement in physical activity and reduction of weight as well. The average weight loss was observed to be between 5% and 10% of the initial body weight, which already indicates positive changes in metabolic health and a decrease in HbA1c levels by 0.5% – 1% thereby reducing the risk for T2DM. In terms of financial implications, it was found that these measures end up being cost-effective due to long-run savings on healthcare expenses. Direct costs such as treatment fees and hospitalization charges were taken into account alongside indirect costs like productivity losses during illness among other non-medical expenditure categories in this study (Alouki et al., 2016). Furthermore, continuous monitoring of biomarkers associated with metabolic syndrome and

NCDs using wearable biosensors will allow for early detection of health problems that can be addressed through interventions and preventive measures (Yanez-Sedeno et al., 2020).

In India, mHealth and telemedicine can be of great help in mitigating the healthcare gap that exists between different parts of the country. This is mainly because they are cheap and easy to get hold of therefore being more favourable in these areas. Moreover, traditional healthcare services may not be available in low-income regions hence making mHealth technology very appropriate for them. (Mohamad and Defi, 2023). The adoption of telemedicine together with mobile health can tip the balance towards a cheaper model that is more involved in preventing illnesses as opposed to treating them, this idea falls in line with global efforts towards value-based care. (Marcolino et al., 2018). To be implemented successfully, stakeholders in India have understood the need to make mHealth systems affordable and cost-effective (Pai and Alathur, 2021). It is important to know what stakeholders think about it and create a basis for starting such a system because this will help in maximizing the benefits that can be derived from using these gadgets to better health care access as well as outcomes. Health service providers should overcome challenges against telehealth and mHealth while at the same time utilizing facilitators so that they can improve the provision of services especially where resources are limited (Sharma, 2023). The potential for transforming the Indian health system using mHealth devices lies in their ability to improve wellness conditions and increase accessibility levels towards medical services while saving money spent on healthcare (Shukla and Sharma, 2016).

As per WHO guidelines, in countries with low- and middle-income, such as India, cheap but effective technologies for NCD prevention and monitoring should be followed. These can work towards strengthening primary health care services to prevent the occurrence of chronic non-communicable diseases or control them better if they happen already (Haque et al., 2020). Additionally, WHO suggests that each country selects those interventions that are efficient based on their economic status coupled with primary health care to reduce morbidity as well as premature deaths arising from major NCDs (Shu et al., 2019).

A study done to examine the application of AI in colorectal cancer screening (CRC) conducted in India established cost analysis in the context of digital health and offers an understanding of the role of AI in enhancing screening programs relevant to colorectal cancer (CRC). According to the study, AI systems are effective tools that improve the detection of colonic polyps resulting in early diagnosis and treatment thus preventing CRC. The evaluation also notes that the integration of AI with screening programs can reduce the utilization of resources, including human and equipment while improving the overall management of health care. The use of efficient digital health tools can lead to decreasing public health care expenditure but at the same time yield better results making a strong claim for the public acceptance of AI. This is in cognizance with the current call for effective screening programs particularly within middle-income countries where such technologies can help overcome hurdles to access and operational productivity within the healthcare system (Rao et al., 2022).

The above results signify that these technologies can improve health monitoring, early identification of health issues, and promote preventative measures which will lead to better health status of people and reduced health spending. For instance, wearables are affordable when it comes to managing diabetes with enhanced exercise as well as the costs linked to it. In addition, this paper highlights the importance of mHealth coupled with telemedicine to fill gaps in the provision of healthcare services to individuals in the below-poverty line areas

through reachable cheap care that is in harmony with the global value-based care system. Apart from that, the study examining the cost-utility of AI in identifying colorectal cancer shows how it can also facilitate the improvement of early detection and, therefore, management of healthcare resources.

Chapter 5: Discussion

The main aim of this study was to analyse the efficiency, safety, and ease of use, of existing DHIs in preventing metabolic syndrome and related non-communicable diseases in India. Metabolic disorders and other chronic non-communicable diseases are rising in India which are causing great concern for public health. Non-communicable diseases like obesity, Diabetes, and hypertension are major precursors of other life-threatening diseases such as cardiovascular diseases, stroke, etc. It is of utmost importance to prevent these conditions, and digital health interventions can be a promising solution in this regard.

It is important to understand the technical aspects of DHIs to deploy them effectively in practice. Interoperability or the capacity for disparate systems and organizations to exchange, interpret, and use data together represents one of those key technical elements. It's critical in India that electronic health records (EHRs) be integrated with mobile health applications (mHealth apps), wearable devices (wearables), and telemedicine platforms. Such integration is made possible by standards like Fast Healthcare Interoperability Resources (FHIR), which provides a framework for exchanging data. But just having new tech isn't enough; policies must also change if we want digital healthcare to make a difference against metabolic disorders and non-communicable diseases (NCDs). A comprehensive regulatory framework needs to be established governing how these technologies are used while always safeguarding patient information (Jain, 2023).

Fast Healthcare Interoperability Resources (FHIR) have been constantly in use by the United Kingdom, Canada, and Germany in their digital health initiatives. The UK has synchronized FHIR into its digital services for ensuring care coordination of children and youth having special health needs (Sinaci et al., 2023). In Canada, the adoption rate of digital health solutions such as EHRs across the country by organizations like Canada Health Infoway which relies on FHIR for interoperable health care (Nan and Xu, 2023). Through the integration of FHIR at 29 university hospitals' data integration centres, Germany's Medical Informatics Initiative is affirming its commitment to FHIR adoption in the country (Gruendner et al., 2022).

The key factors for the success of digital health interventions in preventing metabolic disorders are user experience, ease of integration into daily routines, and adherence to healthy behaviours. Intuitive and captivating health applications need to be built on principles that are user-centred. User engagement can be boosted by incorporating features like gaming elements, progress tracking as well as reminders. Israel can be viewed as an example of this. Metabolic syndrome and non-communicable diseases have been successfully tackled through digital health interventions in Israel. This country has brought forth new and creative ways of using technology in the medical field. For instance, a lifestyle intervention that was culture-sensitive among obese Arab women in Israel proved to be effective since it increased physical activity levels and improved metabolic syndrome (Merom et al., 2012). This showed how important it is for interventions to consider different cultures when trying to change people's behaviour toward health or even address the risk factors of metabolic syndrome.

Promoting health through digital platforms which include gamified platforms has also been promising in educating on prevention of metabolic syndrome, obesity as well as type 2 diabetes mellitus (Incontri Abraham et al., 2022). In fact, by combining game features with

digital health initiatives, Israelis have managed to involve more individuals in learning about their health thus changing some behaviours and leading to better results.

There is a lesson India can learn from this Israeli strategy for enhancing health literacy so that its citizens can engage themselves in healthy habits preventing metabolic syndrome along with other related NCDs. Israel's personalized interventions regarding lifestyle changes such as those shown by culturally sensitive lifestyle interventions emphasize tailored approaches when dealing with metabolic syndromes and NCDs (Merom et al., 2012). These services were designed based on individual needs hence the ability for these patients' involvement in the self-management of their conditions was achieved. Therefore, targeted healthcare strategies for people who are prone to developing metabolic syndrome should bring forth desirable outcomes as seen in India after studying this kind of personal involvement used by Israel in its healthcare system.

Ubiquitous mobile devices and wearables that track physical activity, diet, and vital signs can help in integrating with daily routines, however, these should also undergo usability testing alongside iterative design processes thus making sure they are friendly to use by all people including those with limited technological skills or knowledge from different cultures.

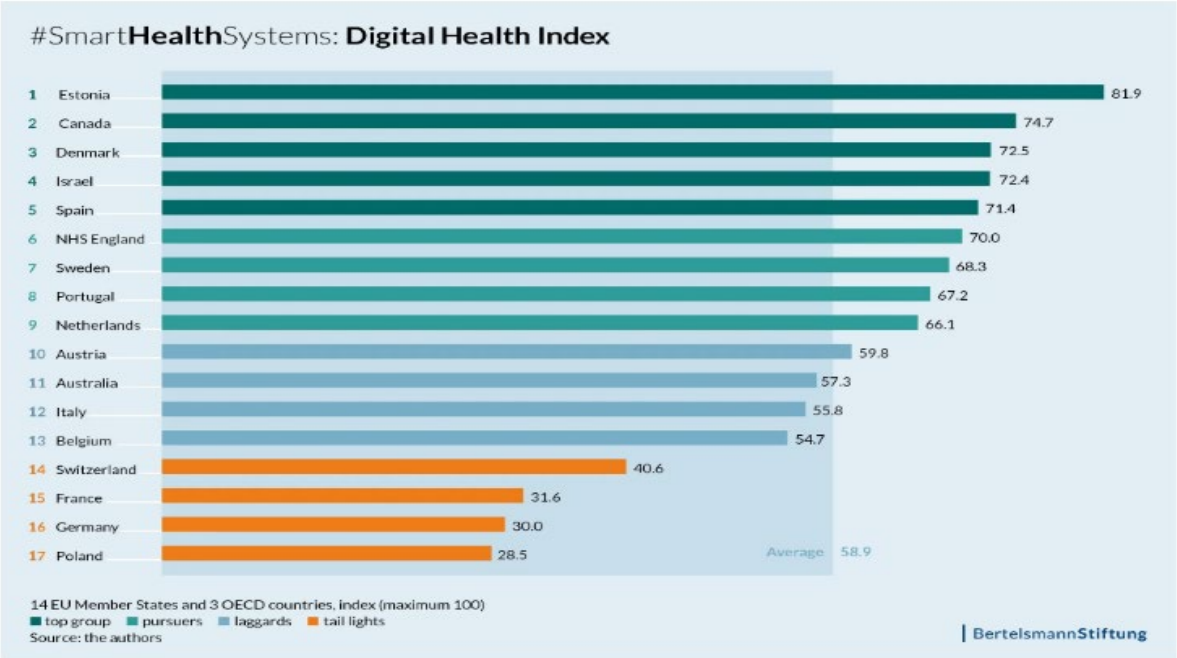

Figure 6:Digital health Index

(source- https://www.programm-gesundheit.blog/en/digital-health-europe/)

Other lessons can be learned from digitally advanced countries like Estonia, Canada, and Denmark, as per the Digital Health Index. Estonia has made significant strides towards digital health innovation hence positioning itself as a global leader in the sphere of digital transformation. The fact that the country's technological-based healthcare system is doing

very well has been recognized across the globe. For example, an obvious sign of this approach can be found in many events and programs arranged by Estonian IT companies. The capability to customize health services using digital platforms makes Estonia excel in digital health interventions. Several studies have proven that personalized digital healthcare services have positive effects on metabolic syndrome risk factors and lifestyle improvements, thus showing the efficiency of such strategies in promoting good health and preventing NCDs (Bae et al., 2023). India can borrow from Estonia's method of personalizing digital health solutions to meet its own people's needs for healthy living while cultivating preventive habits.

In Canada, digital health interventions have played a pivotal role in the prevention of metabolic syndrome and related NCDs. The country has adopted a variety of creative strategies to address these health problems. For example, Canadian Heart Health Surveys were critical in describing the prevalence of metabolic syndrome in Canada and testing guidelines for predicting metabolic risk factors (Ardern et al., 2003). Besides, the Canadian Health Advanced by Nutrition and Graded Exercise (CHANGE) program was created to be delivered by multidisciplinary teams within primary care; this shows an interdisciplinary approach towards managing obesity and metabolic syndrome (Sturgiss et al., 2018).

The development of a Dietary management care map for metabolic syndrome is one way that Canada has demonstrated its commitment to personalized intervention strategies aimed at facilitating health behaviour change and dietary modification among individuals with metabolic syndrome (Royall et al., 2014). These initiatives have led to improved outcomes in terms of health as well as reduced risk factors associated with metabolic syndrome. Canada's active support for monitoring progress on digital health through participation in activities organized by bodies such as the OECD or Commonwealth Fund indicates that it is serious about advancing digital healthcare initiatives (Gheorghiu and Hagens, 2016). Also noteworthy are the positive results seen from lifestyle interventions implemented through programs like CHANGE which have shown effectiveness at reducing individual health risks while improving management practices dealing specifically with Metabolic Syndrome risk factors (Namen et al., 2019). This proves how valuable these programs can be when tackling growing burdens posed by both metabolic syndrome and NCDs within countries such as Canada.

There are many things that India can learn from successful Canadian digital healthcare projects aimed at preventing metabolic disorders accompanied by non-communicable diseases. For example, using multidisciplinary approaches similar to those found within the CHANGE program will help strengthen primary care services leading to better collaboration between different professionals involved in Indian healthcare systems (Sturgiss et al., 2018). Furthermore, India may use personalized intervention based on dietary management strategies developed in Canada so that they promote changes in lifestyles among people who are prone to metabolic syndrome (Royall et al., 2014).

Preventing metabolic syndrome and NCDs in Denmark has been facilitated by digital health interventions. These health challenges have been addressed with innovative strategies by the country thereby showing how technology can be used in healthcare. For example, the Danish "11 for Health" program has been effective in creating awareness about health, well-being, and physical fitness among school children from ethnic minorities which is essential for addressing health promotion to improve the state of health of the children (Ryom et al., 2021). Additionally, equity-based focus in digital healthcare within Denmark has started a

conversation on addressing disparities and challenges that exist within digital health; thus, giving insightful suggestions on how to improve access to care and outcomes (Eriksen, 2023).

Moreover, personalized interventions such as the “11 for Health” program are central to Denmark’s approach to promoting behaviour change and improving knowledge about metabolic syndrome among people at risk (Ryom et al., 2021). This way, Denmark has managed to reach out effectively to individuals through the customization of health services. Hence India should borrow a leaf from Denmark in its personalized interventions especially when it comes to meeting specific needs of its people concerning healthcare while also looking for ways of preventing disease.

Therefore, such platforms as the “11 for Health” program make it possible for the residents of Denmark to not only improve their levels of knowledge but also their well-being because they are essentially digital tools that may be used by youngsters rather than elderly people (Ryom et al., 2021). Consequently, India can incorporate digital health platforms into their efforts aimed at promoting public health by boosting healthy behaviors; increasing health literacy levels; as well as reducing the incidence rate of hypertension that is associated with metabolic disorders. It means that if India uses technology to educate patients about diseases or make them adopt good lifestyles then the decision-making process will become easy. This particular initiative called “11 for Health”, proves that Denmark focuses on lifestyle interventions and health promotion programs (Ryom et al., 2021). By taking a holistic approach to the matter of physical education, dietary habits, and healthcare knowledge, India can upgrade its healthcare system as well as improve health in society generally. Therefore, it is not hard for India to develop such programs if it learns from Denmark’s initiative that was aimed at enhancing literacy levels in relation to the health of the population, including children.

A major driver in the adoption of DHIs is their cost-effectiveness. For example, in India where many people may not have large amounts of money to spend on healthcare services, low cost becomes very important. Mobile health applications and telemedicine services are cheap because they do not require much infrastructure like traditional healthcare facilities. Another point is using mobile networks that already exist with smartphones being widely used can save initial investments.

Another strength of DHIs is scalability. Digital platforms can be expanded quickly so that they reach a large number of people who would otherwise lack access to preventive care services. As more users sign up, economies of scale will cut down on per-person costs even further. Additionally, these types of interventions could also be made relevant across communities by considering and accommodating regional or cultural variations.

Furthermore, digital health initiatives have the potential for creating long-term economic benefits by reducing the burden metabolic disorders place on healthcare systems alongside NCDs which they trigger. By intervening early and continuously monitoring patients’ condition, costly treatments and hospital admissions can be avoided thereby saving individuals as well as the whole system substantial amounts of money. Better health outcomes lead to improved productivity levels at work while also cutting down on days taken off sick thereby contributing towards economic growth as a whole.

In India, there are many problems that DHIs have to overcome. One of these problems is the digital divide which refers to the uneven distribution of technology among different groups in a population. For this reason, it is necessary to increase digital literacy and expand internet connectivity into rural areas. Also, security and privacy issues around data can be another big challenge. This involves making sure that strong data protection measures are in place and followed according to laws like the Personal Data Protection Bill so that people can trust them with their health information.

The European AI Act that came into effect on August 1, 2024, is going to make the healthcare industry better as it creates a risk-based law that puts patient safety first and encourages responsible Artificial Intelligence (AI). According to the new act, high-risk AIs including those used for medical applications must meet strict requirements like ensuring quality data sets, implementing strategies for mitigation of risks, and having human supervision among others. This will create trustworthy technologies powered by artificial intelligence that can enhance health outcomes as well as services around them. In addition, the legislation requires transparency from these systems where they have to let users know when they are dealing with an intelligent system thus creating trust in such technologies (*AI Act Enters Into Force, 2024*). India may borrow lessons from this framework by taking up a similar risk-based strategy, laying down clear guidelines concerning AI in healthcare while prioritizing human rights issues together with openness towards its application among other things. Besides, there should be the establishment of a separate regulatory body charged with overseeing the deployment of artificial intelligence so that innovations within healthcare can be done safely without compromising ethical standards. If all these principles were adopted, then it would help build safe environments for innovative ecosystems involving intelligent machines aimed at improving the delivery of healthcare services provided to patients in need.

Integration with the current healthcare system poses its own set of challenges too. Hospitals should universally adopt interoperability standards while training all health practitioners on how best to use various digital tools at their disposal for effective caregiving. Furthermore, seamless integration calls for joint partnerships between government bodies, private sector players, and healthcare workers thus forming a holistic digital health ecosystem.
Finally, Sustainable funding models must be put in place if we want DHIs to grow and last longer. Government grants together with private sector investments through public-private partnerships could offer financial support needed for development stages as well as maintenance phases. Additionally, showing stakeholders the cost-effectiveness and positive health outcomes of such systems will attract more investments and support.

5.1 Limitations & Strengths

Here are the major study limitations that include; while researching the impact of digital health interventions (DHIs) for the prevention of metabolic disorders and other non-communicable diseases (NCDs), it was difficult to find or establish a few, or at times no research studies on the subject. The following are some of the reasons why this gap in the literature could be observed: Firstly, the possible problem of low availability of published studies or narrowing their focus to the examination of the preventive role of digital health in this regard. In another case, it could be due to publication bias where research findings that failed to reach or produced negative results are published less. In addition, while evaluating the DHIs on technical criteria, there were concerns that research at the Indian lens was sparse.

It is worth noting that most of the existing DHIs in the Indian market are mainly focused on the disease treatment side rather than prevention. This trend could be interpreted as a trend in the overall healthcare approach where there is slightly more focus on treatment measures compared to precautions. That could have played a role in shaping and applying DHIs to lean more on response and control of conditions as they arise rather than their prevention.

Chapter 6: Conclusion And Recommendations

India has a large population and high demographic diversity, besides there is a growing incidence of metabolic syndrome and NCDs, putting a lot of pressure on the country's health care system. Another challenge is the skewed doctor-patient ratio which has a negative bearing on the availability and quality of health care to the populace in both the urban and rural centres. In this regard, there is an opportunity for digital health to catalyse roles in the prevention, early diagnosis, and control of NCDs that are assuming more importance in Indian healthcare systems.

At the moment, there is limited healthcare prioritization in preventive care and more of a focus on the cure for diseases, particularly NCDs, in India. While this curative-focused approach is crucial, it does not address key aspects of early detection and prevention strategies that could help avert or at least postpone such perpetual illnesses. For that reason, the change in focus towards prevention of diseases is not only preferable, but also necessary due to the burden that NCDs cause to individuals, families, and the healthcare system. Understanding the approaches to NCDs could prevent their future occurrences aided by digital health, which would enhance the well-being of patients and decrease expenses in the long run.

Indian government has put a lot of effort in establishing digital health initiates by launching the Ayushman Bharat Digital Mission (ABDM) and eSanjeevani. These programs are aimed at increasing options for treatment and offering a coordinated approach. However, they tend to focus more on curative care rather than prevention in the current society. To maximize the benefits that come with the use of digital health to prevent NCDs, it is necessary to employ a more balanced model of management of this disease that also incorporates prevention. However, the place of the private health-tech firms in this setting remains equally important.

These companies have come up with diverse digital health initiatives (DHI) including preventive measures against NCDs; apps and platforms that encourage healthy living, keep an eye on chronic illnesses, and even guide individuals on what to eat based on their body characteristics. However, the effectiveness of these DHIs requires the enhancement of its merits assessment. Some of the critical issues that need to be evaluated to ensure trust with the stakeholders include data security, privacy, and transparency. Lack of protection and clear policies on handling data may prevent the effective use and integration of these tools, thus lowering their effectiveness.

Based on the analysis of the study, some recommendations to improve DHI in Indian setting for public and private sector stakeholders:

1) Development of Comprehensive Policies for Preventive Healthcare.
   Target Audience: Government Health Ministries, Policymakers, and Public Health Experts.
   Recommendation: Prevention should take the front seat in a country's national health strategy since it is the most important part. To achieve this, there should be policies requiring the use of preventive tools in different digital health platforms; the national agenda must also include targets to reduce non-communicable diseases (NCDs) and allocate resources towards building and advancing things that are meant for

preventive health programs. Policymakers need to involve experts who are experienced in public health when formulating these policies so that they may be evidence-based and incorporate best practices.

2) More Focus on Preventive Healthcare
   Target Audience: Government Health Agencies, Digital Health Developers, and Healthcare Providers.
   Recommendation: Prevention of diseases is better than cure hence there is a need for digital platforms to have resources that are specifically meant for prevention. The Ministry of Health together with developers should incorporate features like risk assessment tools, knowledge on lifestyle changes through educative content as well as early detection systems into the already existing or new digital healthcare solutions while also encouraging medical practitioners to use these alongside traditional treatments.

3) Data Security and Privacy
   Target Audience: Policymakers, Digital Health Developers, and Regulatory Bodies.
   Recommendation: There is a need for strict measures when it comes to the protection of data which may be personal but stored within various applications used in this field whether by the government or private sector; hence this is one area where policymakers along with enforcers must work hard until protocols are put in place so that every individual's information can be safeguarded against unauthorized access. Encryption methods should be strong enough to ensure that no one can hack it easily during the storage process while at the same time, transparency is enhanced through clear usage policies about what each party does with collected patient data thus enabling them to know its safety level always. Regular checks plus certifications should also apply here for compliance purposes besides creating trust among users who might want their records handled securely.

4) Interoperability and Integration
   Target Audience: Health IT Departments, Digital Health Developers, and Healthcare Institutions.
   Recommendation: Different IT systems employed by hospitals must become able to communicate easily without any hiccups because sometimes patients may have been attending different clinics before being admitted into one hospital; therefore, if all these were interconnected then sharing patient records would not pose a problem thus making sure that care is continuous. Health institutions need to adopt these integrated systems to provide holistic treatments for all their clients in a more efficient manner.

5) Public-Private Collaboration
   Target Audience: Government Agencies, Private Health Tech Companies, and Industry Stakeholders.
   Recommendation: There is a need for partnership between public health agencies with private companies dealing in technological gadgets related to medical services since it will help them come up with more advanced preventive health solutions against NCDs. This can include joint research ventures where knowledge from both parties could be shared equally among other possible benefits like sharing resources needed or even forming public-private partnerships aimed at scaling up successful interventions already done by either side involved thus ensuring wider coverage.

6) Patient Education and Engagement
   Target Audience: Healthcare Providers, Digital Health Platforms, and Community Health Workers.
   Recommendation: Medical practitioners should develop programs that foster education as well engagement among patients through the creation of friendly interfaces on these digital platforms where they can easily access information concerning their wellbeing; additionally, there should also be frequent follow-ups made by community health workers who are trained about the importance of using them effectively when providing services involving prevention of diseases. This will ensure that most people are aware of it leading to high adoption especially among those living in the outskirts, far from established healthcare centres.

This, in turn, will allow India to develop a much better and finely tuned strategy for the management of NCDs and make preventive healthcare a priority of its efforts. Hence, the adoption of digital health solutions for NCDs as well as situating it as a central facet of the healthcare system has the ability to not only reduce the burden of NCDs and more broadly, the health threats they pose but could also catalytically reshape health prospects of the nation.

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Annexure 1: List of keywords

Digital OR mHealth OR eHealth OR Online OR Mobile Health OR Telemedicine OR Telehealth OR Wearables OR Biosensors OR AI OR Health information exchange	AND	intervention OR Lifestyle intervention OR plan OR program OR initiative OR policy OR application OR strateg* effectiveness OR interoperability OR user experience security OR cost OR Cost-effectiveness OR reliability	AND	non-communicable diseases or cardiac OR diabet* OR hypertension OR metabolic syndrome OR abdominal obesity OR obesity OR high cholesterol OR chronic diseases	AND	Prevention OR Health outcomes OR Effects OR Impact OR Weight loss OR	AND	India Estonia OR Canada OR Israel OR Denmark OR developed countries OR western countries OR United Kingdom OR OECD