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Assignment Cover Sheet

Learner name(s):	**FEBY MATHEW**		
Learner number(s):	[redacted]		
Assignment Type:	**Individual: ✓**	**Group:**	**COHORT 5**
Course:	**MSC DIGITAL TRANSFORMATION**	**Stage/year:**	**2024 - 2025**
Module:	**DISSERTATION THESIS**		
Study Mode:	Full time ✓	Part-time	
Supervisor Name:	**DINESH REDDY**		
Assignment Title:	**EXPLORING THE USE OF IoT-ENABLED BIOSENSORS FOR DIABETES CARE: PERSPECTIVES FROM INDIAN PATIENTS**		
No. of pages:	**89**		
Uploaded to Moodle:	Yes ✓	No	
Additional Info:			
Date due:	**24/08/2025**		
Date submitted:	**_24/08/2025_**		

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EXPLORING THE USE OF IoT-ENABLED BIOSENSORS FOR DIABETES CARE: PERSPECTIVES FROM INDIAN PATIENTS

By

FEBY MATHEW

3151657

A thesis submitted in partial fulfilment of the requirements for

MSc in Digital Transformation (Life Science)

Innopharma Faculty of Pharmaceutical Sciences

Griffith College Dublin

August 2025

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DECLARATION

Candidate Name: FEBY MATHEW

I hereby confirm that the dissertation entitled "*Exploring the Use of IoT-Enabled Biosensors for Diabetes Care: Perspectives from Indian Patients*", submitted for the degree of MSc in Digital Transformation (Life Science), is a research work carried out by me, and that all sources used have been acknowledged using complete references.

Candidate Signature:

Date: 24/08/2025

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Supervisor Signature:

Date: 24/08/2025

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my supervisor, Dinesh Reddy, for his invaluable support, encouragement, and guidance throughout this dissertation. His insightful feedback and unwavering patience were instrumental in shaping the direction and completion of this work.

I am also deeply thankful to all the lecturers at Innopharma and Griffith College for their dedication and commitment to our academic journey. My heartfelt appreciation goes to my classmates for their collaboration and motivation, and to all the survey respondents who took the time to contribute to this study. Their input was crucial in making this research possible.

Lastly, I would like to extend my deepest appreciation to my family and friends for their endless love, understanding, and support throughout the process. Their belief in me has been a constant source of strength, and I will remain forever grateful.

I submit this work to the grace of God Almighty, for blessing me with health, confidence, and knowledge to carry out the whole work successfully.

FEBY MATHEW

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
API	Application Programming Interface
CGM	Continuous Glucose Monitoring
CPU	Central Processing Unit
GDPR	General Data Protection Regulation
GPRS	General Packet Radio Service
GUI	Graphical User Interface
HbA1C	Haemoglobin A1C
HCP	Health Care Professional
HIPAA	Health Insurance Portability and Accountability Act
ICT	Information and Communication Technology
IoT	Internet of Things
IP	Internet Protocol
ISF	Interstitial Fluid
IT	Information Technology
mHealth	Mobile Health
ML	Machine Learning
NFC	Near Field Communication
PHI	Protected Health Information
QOL	Quality of Life
RCT	Randomized Controlled Trial
SDK	Software Development kit
UI	User Interface
WHO	World Health Organisation

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ABSTRACT

“EXPLORING THE USE OF IOT-ENABLED BIOSENSORS FOR DIABETES CARE: PERSPECTIVES FROM INDIAN PATIENTS”

Feby Mathew

The research presented the extremely high potential of IoT-based biosensors to revolutionise diabetes treatment in India. With real-time constant monitoring of blood glucose levels, the sensors can have the capacity to empower patients to achieve better evidence-based self-management. This study examined awareness and uptake of Indian diabetic patients towards embracing such equipment, the benefits they accrue from it, and challenges that are associated with mass adoption. Special attention was given to distinguishing between the urban and rural environments and the influence of digital literacy, socio-economic status, and cultural beliefs towards uptake. A mixed-method design was employed that integrated quantitative survey answers of 151 patients with qualitative open-ended responses. The respondents were adult patients with Type 1 or Type 2 diabetes who had ever used or were exposed to IoT-based biosensors such as Freestyle Liber, BeatO, or Bionime. Quantitative measures revealed trends in use/ level of satisfaction and outcomes experienced, while repeated themes tended towards identified barriers and user experience. It was proven that the patients cherished the potential of the biosensors to monitor non-invasively and in real-time blood sugar levels in the body, detect anomalous fluctuations, and directly assist the health care practitioners. The majority of the participants exhibited superior disease insights, an earlier treatment adjustment, and self-management confidence. Pre-existing social culture that favoured doctor-directed care also worked, mainly among older and less technologically inclined population groups. The study ends with the reflection that the biosensors made using IoT are already performing well as the tools of monitoring diabetes and have already been adopted by multiple users, still, multi-dimensional intervention would be critical in order to ensure sustainable adoption at the country level. These include subsidies by the government or insurance, training programs that hold cultural relevance, connectivity within rural areas, interfaces in local languages, and inclusion within the national health missions like the ABDM. The potential of IoT biosensors as the cheapest and patient-centred devices that will help overcome the diabetic burden in India can be popularised by overcoming technological and social-cultural barriers that arise.

CHAPTER 1

INTRODUCTION

1.1 Brief Background

Epidemic increases in chronic non-communicable diseases such as diabetes mellitus have become a significant challenge to healthcare systems worldwide, with extremely severe consequences in developing countries such as India. Diabetes is a permanent metabolic disorder that destroys the body's ability to regulate blood glucose levels, leading to severe complications when not managed appropriately. In India alone, 77 million individuals have diabetes, and this is projected to rise continuously in the coming years (Kesavadev *et al.*, 2021a). The disease requires rigorous, regular monitoring and timely interventions in order to prevent conditions such as neuropathy, nephropathy, retinopathy, cardiovascular disease, and, in severe cases, death.

1.2 Context of the Study

Conventional methods of blood glucose monitoring, which rely primarily on finger-stick glucometers, have several limitations. These methods are invasive, objectionable to patients, and most often underutilised because they are inconvenient or unavailable (Sabharwal *et al.*, 2022). In rural or low-resource settings, these disadvantageous factors are further exacerbated by low infrastructure, low awareness, and poor resource availability (Kanwar *et al.*, 2023). There is thus an urgent need for other monitoring methods that are patient-friendly, inexpensive, and adaptable to various socio-economic conditions. Moreover, the novel coronavirus, or COVID-19, pandemic further exposed other vulnerabilities in traditional healthcare supply systems, such as hospital visits and contact-based tests, which became riskier and scarcer. This added more pressure to introduce remote and automated methods (Peyroteo *et al.*, 2021).

1.3 Significance and Justification of the Study

With the emergence of the digital age, healthcare has begun implementing sophisticated technology to enhance disease control. A good example of such innovative technology is the Internet of Things (IoT)-based biosensor, a crucial component of the larger digital health platform (Farooq *et al.*, 2023). Biosensors are small, portable, and can continuously monitor physiological readings, like glucose levels, and transmit the same in real time to cloud platforms or smartphones. IoT-based biosensors allow patients to make timely and knowledge-based decisions regarding their health through real-time feedback, trend analysis, and alerts. Meanwhile, they facilitate physicians to monitor patients remotely, intervene earlier, and more personalise treatment regimens.

Freestyle Liber, BeatO, and Bionime are some devices that have begun gaining traction in India, especially in cities where healthcare infrastructure and digital penetration are robust. These devices offer non-invasive or minimal invasiveness, smartphone app compatibility, and ease of use and therefore resonate with tech-savvy patients. However, the spread of such technologies is not pan-nation-wide. The rural-urban digital divide, differences in health literacy, and socio-cultural variables are the primary barriers to their widespread deployment (Inampudi *et al.*, 2024). Rural patients in particular may be denied access to not only devices but also internet connectivity, along with the support infrastructure required for the maintenance of use.

Moreover, the lack of public knowledge about digital health solutions, combined with a lack of clinician education on how and when to use biosensor data in care, adds further complexity to implementation. Data privacy concerns and ethical use of gathered health information from connected devices are also of concern (Farooq *et al.*, 2023). Patients will not choose such devices if they are still sceptical about how their personal health data is managed, accessed, and secured. In addition, the majority of consumers still trust traditional physician-centred care compared to electronic media (Mishra *et al.*, 2024).

Also, there have been no studies conducted that explore Indian diabetic patients' attitudes, perceptions, and concerns regarding the use of IoT-enabled biosensors. Foreign literature overemphasises the clinical efficacy of Continuous Glucose Monitors (CGMs) but underemphasises contextual factors such as cost, digital literacy, cultural acceptability, and Indian health infrastructure. In this context, the present research endeavours to bridge this gap through an exploration of how Indian patients engage with, view, and are affected by the introduction of IoT-based biosensors into daily life. The research is user-centred in attempting to determine not just if such technologies are clinically efficacious, but if they are viable, usable, and sustainable for everyday individuals.

1.4 Why This Topic and How It Relates to the Module

This project has a very direct relevance to the MSc Digital Transformation (Life Sciences) programme as it analyses how biosensors based on the Internet of Things could transform diabetes care in the case of a low- and middle-income country like India. It is related to modules like Digital Health Strategy, Technology and Innovation for Health Outcomes, and Healthcare System Transformation, which include user-centricity, scalability, and local contextualisation. Being patient-focused puts into perspective basic questions like digital divide, cost, and data privacy, challenging underlying assumptions for health ethics and equity.

The study contributes to studies on digital health uptake in low-resource settings and offers policymakers, developers, and clinician's pragmatic recommendations. The study also offers insights for scaling digital health technology, including mobile health, wearables, and remote monitoring, and points out patient-centred design and contextual flexibility as being key elements of international digital health initiatives.

1.5 Scope of the Study

This study attempts to bridge the gap between technology innovation and patient-specific care via the investigation of the adoption of IoT-based biosensors among actual Indian diabetic patients. It will attempt to address the scope in various dimensions:

Technology Adoption: The study will consider the extent to which diabetic patients adopted the technology of biosensors, i.e., the devices they use, usage rate, and the most significant features used by the users.

User Experience and Engagement: It will examine how users make use of such devices, how they feel about using them, how easy or hard it is to use them, and the perceived impact on managing the disease.

Digital Literacy and Accessibility: It will examine the digital literacy factor to use a smartphone and be online in determining user usage of biosensor devices.

Socioeconomic and Cultural Context: How education, income, and culture will determine the integration of technology will be addressed.

Policy and Integration of Technology into Systems: The implications for integrating biosensor technologies into overall healthcare delivery systems, like telemedicine, electronic health records, and national health programs, will be addressed.

1.6 Aim of the Study

To explore the experience, perceptions, and challenges of Indian diabetic patients in adopting and using IoT-based biosensors for disease monitoring and self-management.

1.7 Research Objectives

•To explore the usage of IoT-based biosensors among diabetic patients in India at present.

•To determine the benefits and limitations of IoT-based biosensor use from the perspective of the patients.

•To identify the areas for possible improvement of IoT-based diabetes control technology in the years to come.

•To assess the degree to which the self-care and quality of life of the patients depend on such devices.

•To examine the level of awareness and digital literacy among Indian diabetic patients regarding IoT-enabled healthcare devices.

•To identify the barriers to adoption (technological, economic, or social) of IoT-enabled biosensors in Indian healthcare.

1.8 Research Questions

What is the current usage of IoT-based biosensors among diabetic patients in India?

What are the benefits and limitations of IoT-based biosensor use from the perspective of diabetic patients in India?

What are the areas for possible improvement of IoT-based diabetes control technology in the years to come, as identified by diabetic patients in India?

To what degree do the self-care and quality of life of diabetic patients in India depend on IoT-enabled biosensors?

What is the level of awareness and digital literacy among diabetic patients in India regarding IoT-enabled healthcare devices?

What are the barriers (technological, economic, or social) to the adoption of IoT-enabled biosensors in Indian healthcare, as perceived by diabetic patients?

1.9 Structure of the Dissertation

The dissertation consists of five chapters as follows:

Chapter 1: Introduction – Provides the background in the context of Indian diabetes, the significance of digital health solutions, and justification, objective, and scope of research.

Chapter 2: Literature Review – Critically examines the existing research in the context of IoT-based healthcare solutions, biosensor technologies, and their application amongst diabetic patients, especially in low- and middle-income countries.

Chapter 3: Research Methodology – Describes the study design, data collection methodology, sampling strategy, and ethical concerns used to study the research objectives.

Chapter 4: Findings and Discussion – Presents the data analysis and discusses significant findings in terms of research questions and literature.

Chapter 5: Conclusion and Recommendations – Records the main conclusions, considers limitations, and offers reasonable recommendations to healthcare players as well as recommendations for future studies.

1.10 Definition of Key Terms

Ayushman Bharat Digital Mission (ABDM): A program initiated by the Government of India to possess one digital health system, e.g., electronic health records and interoperability between health service providers.

Continuous Glucose Monitoring (CGM): A small wearable sensor to continuously track glucose levels during the day and night and provide trend data and alarm notifications.

IoT Biosensor: A biosensor connected with IoT technology for the real-time transfer of health data to associated platforms such as smartphones, cloud servers, or dashboards for healthcare providers.

Internet of Things (IoT): A system of devices with sensors and computer programs that collect and transmit data through the web without human interaction.

CHAPTER 2

LITERATURE REVIEW

2. Introduction

The Internet of Things (IoT) has changed the world of healthcare to a significant degree, especially in the treatment of chronic diseases such as diabetes. A good solution can be used in India, where diabetes is prevalent, and these IoT Biosensors enabled by applications have a huge potential. The technologies allow continuous glucose monitoring (CGM), which gives a real-time reading of glucose levels that are synced with mobile applications and cloud-based data. As (Mishra *et al.*, 2024) point out, bio-sensing devices could be used to elevate the framework of digital health systems and improve the process of treating diabetes through early interventions and prevention of complications.

Even though some progress has been made, a literature review shows that the situation in India still lacks the practical aspect of implementation of the biosensors based on IoT technology, and their results can be related to the lack of socio-economic background, digital literacy, and health access factors. Although (Kapur *et al.*, 2023) and (M Saravanan *et al.*, 2022) research concentrates on the technological possibilities of the devices in question and their role in changing patient outcomes; these studies usually neglect the obstacles that patients have to overcome on the way, such as the affordability of electronic gadgets, technical literacy, and the healthcare system infrastructure. This is a particularly important problem in rural India, where most diabetic individuals reside, and the experience with digital tools is unlikely to go well because of extremely low access and digital literacy.

Moreover, the perceptions of Indian patients towards IoT-enabled biosensors, such as usability, accessibility to user-friendly features, and how to integrate the biosensors into current healthcare procedures, have not been researched in detail. Although (Parihar *et al.*, 2023) speak about the potential use of IoT in the field of public health, little attention is paid to its use in managing people with diabetes in India. The proposed review will fill such gaps by evaluating the available literature and exploring adoption issues that are contextually specific to Indian situations.

Key themes explored include: (1) the IoT system in healthcare, particularly biosensor integration in diabetes care; (2) the advantages for patient outcomes; (3) barriers such as socio-economic factors, digital literacy, and infrastructure; (4) patient awareness and perceptions; and (5) the future role of IoT biosensors in healthcare. By analysing these areas, this study provides valuable insights into the current and future use of IoT in diabetes care in India.

2.1 IoT Technologies in Healthcare

Internet of Things (IoT) has experienced a fast rate of development in the health sector with regard to chronic illnesses such as diabetes, as it offers constant, real-time monitoring that is superior to antiquated practices. According to (Li *et al.*, 2024), one of the promising applications of biosensors integrated into IoT is the treatment of diabetes, since by combining these properties of biosensors with mobile applications and cloud systems, one can monitor glucose in real-time. Patients can receive their immediate feedback via this system with the purpose of responding to their glucose level changes in time and thus preventing such complications as hypoglycaemia or hyperglycaemia. The capacity to transfer data in real-time, which (Li *et al.*, 2024) find important, is also what gives a considerable benefit in comparison to the conventional methods of monitoring and, consequently, more efficient management of the disease.

Nevertheless, there are several challenging issues that (Li *et al.*, 2024) do not touch upon, namely, the security of the information, its affordability, and accessibility, particularly, when it comes to such a country as India, with unequal access to healthcare. A study of (Dang *et al.*, 2023) extend the argument and not only talk about technological accomplishments but also address the issue of the large-scale adoption of IoT. They pay attention to the prospects of implementation of IoT and AI, and data analytics that can achieve more individual and responsive care plans and models of healthcare. However, they also express concerns regarding the necessity of digital literacy and data integration as the requirements of successful IoT integration into healthcare.

Along with these developments, (Dang *et al.*, 2023) it also covers such issues as integration and security risks related to the large-scale implementation of IoT in the healthcare industry. As (Li *et al.*, 2024) leave these aspects unexplored, which means that their knowledge on the successful implementation of the use of these technologies in socioeconomically diverse environments is not as profound.

A study of (Chataut *et al.*, 2023) provides more conservative views, admitting that IoT is promising in patient care, but stating the fact that obstacles to the mass usage of this technology currently remain substantial. The problems they emphasise are reliability of the gadgets, consistency over time and security hazards. As (Chataut *et al.*, 2023) point out, the promising opinion on the potential IoT adoption is too far-fetched because effective implementation has to be based on a robust infrastructure, a user-friendly interface, and solutions to the data privacy issues. Unlike (Dang *et al.*, 2023), which focuses on the implementation of AI, (Chataut *et al.*, 2023) emphasise the significance of usability (namely the understanding ability of IoT devices feedback by the patients).

A study of Mishra and Singh, (2023) also note a disparity between the potential of IoT and the realities of using technologies in land-poor creating a situation in India, a location with a deficiency of resources. They focus major in the issues of poor access to digital tools, unstable internet connection, and patchy electricity. Such obstacles are quite different when compared to the optimal implementation of IoT in hospitals in the city, as studied by (Li *et al.*, 2024) and (Dang *et al.*, 2023). As much as these research studies are proficient towards justifying the utility of IoT in the context of the complex environment, the proposed works are not insightful on how such technologies can be deployed to scale to low-resource environments.

According to (Mishra and Singh, 2023) and (Chataut *et al.*, 2023), to popularise the IoT technologies, such factors as cost, digital illiteracy, and poor infrastructure must be overcome. A study of (Mishra and Singh, 2023) in particular, comment on the importance of government intervention in developing the required infrastructure, and this aspect is not mentioned by (Li *et al.*, 2024) and (Dang *et al.*, 2023). These reflections prove invaluable in the introduction of IoT into the Indian environment, with its varied socio-economic spectrum, where rural regions are affected in distinctive ways.

No doubt, the technological potential of IoT in healthcare, presented by (Li *et al.*, 2024)and (Dang *et al.*, 2023), is remarkable, yet the more down-to-earth perspective of practical difficulties is elaborated by (Chataut *et al.*, 2023) and (Mishra and Singh, 2023). A successful combination of the IoT in care of diabetes and particularly low-resource nations, such as India, relies on mitigation of such challenges. Scaling these technologies and making sure they are widely used will depend heavily upon concerns related to affordability, accessibility, and digital illiteracy.

2.2 Benefits of IoT-Based Biosensors in Diabetes Care

In their article, (Hosain *et al.*, 2024) propose an in-depth analysis of the application of IoT-enabled biosensors to real-time monitoring and early diagnosis of chronic illnesses (such as diabetes) illnesses. They focus on the fact that continuous glucose monitoring (CGM) systems are beneficial in the treatment of diabetes to the extent that they are invaluable. A study of (Hosain *et al.*, 2024) mentions that thanks to these devices, patients to see their blood glucose levels change in real-time, which contributes to the improvement of glucose control and thereby decreases the likelihood of the long-term complications of diabetes in the form of diabetic retinopathy and diabetic nephropathy greatly. They explain the functionality of the IoT system as it gathers the information constantly and transmits it to a cloud environment where it will be analysed by both the patient and his or her doctor or specialist. The authors contend that such intensity of monitoring will enable patients to intervene in time and their self-management as a whole.

Although (Hosain *et al.*, 2024) present sound arguments regarding the clinical advantage of the IoT devices, the analysis fails to reflect the issues related to scaling the utilised technologies in the low-resource environment. Although the paper is comprehensive in explaining the benefits within an optimal setting, the analysis is incomplete in assessing issues of expenses and digital literacy levels that may limit the implementation in some countries, such as India, with its healthcare facilities are generally weak. This is a huge gap because the practical application of such devices in real-world settings would depend on how affordable and easy to operate they would be among the various types of patients.

In contrast to (Zou *et al.*, 2024), in the (Hosain *et al.*, 2024) article, the same real-time data monitoring characteristics can be traced, though rather deeply the multi-parameter monitoring systems. This integration of IoT-enabled glucose monitoring with blood pressure and heart rate monitors/sensors, and other perspective biometric sensors (Zou *et al.*, 2024) facilitates a fuller and complete way of managing diabetes. The system they are integrated can assist healthcare providers to modify treatment plans not only according to the level of glucose but also in overall cardiovascular and metabolic health. This comprehensive nature of monitoring provides a better view of patient health, which is particularly necessary in the treatment of complex chronic diseases such as diabetes.

Nevertheless, although (Zou *et al.*, 2024) elaborate on the multi-parameter advantages of IoT systems, they also fail to discuss how these devices are welcomed by the patients in the resource-constrained setting. Both articles demonstrate the possibility of better results, but cannot assess to what extent they depend on the availability of technology and patient education due to the lack of its measurement. This gap is also addressed by (Kapur *et al.*, 2023), who stress the significance of such early detection systems as Diabetic Sense to find care solutions using a breath-based multi-sensor technology to detect diabetes. The result of this less invasive mechanism would be to increase patient compliance due to less discomfort as opposed to conventional blood drawing mechanisms.

A study of (Kapur *et al.*, 2023) offers an in-depth argument concerning the idea of early intervention, claiming that an early diagnosis using devices able to detect early symptoms of diabetes or even pre-diabetes can also prevent more problematic problems later on. This fits together with the results provided by (Hosain *et al.*, 2024) regarding the necessity of continuous monitoring and places more importance on the issue of early stages of detection and its beneficial effect toward healthcare expenditure by eliminating the possibility of more serious outcomes. A study of (Kapur *et al.*, 2023) still fails to discuss the socioeconomic issues that could inhibit the use of such devices on a large scale. They expect more of the technology than how it can be inserted into real-life healthcare systems, especially in low-income populations.

A study of (James and Musah, 2025) take this discussion further, explaining that AI-enabled biosensors, combined with the IoT platforms, will be able to give dynamic customer feedback to both patients and care professionals, which will enable more personalised attention. Their rationalisation is that, through machine learning, it is possible to foresee the spikes and dips in glucose, and real-time changes in pharmaceutical or food suggestions can be made. According to them, this strategy has the potential to create tremendous improvements in the field of patient empowerment by providing patients with not only real-time but also actionable information that would enable them to better control by themselves.

Nevertheless, (James and Musah, 2025) are not more specific about the scalability of such AI-based solutions, especially in the environment with poor access to technology and underdeveloped healthcare infrastructure. Their results are powerful in high-resource areas, but like the rest of the studies, they do not take affordability and digital literacy challenges into account in those areas where technology access is not established. This creates a serious vacuum of knowledge on how the AI-driven systems could be effectively introduced to the resource-constrained countries that lack data connectivity and do not have adequate healthcare infrastructure in place. The parallels between these sources allow us to notice that one of the apparent gaps in the research resides in the volume of enthusiasm fostered by the potential of IoT-enabled biosensors to enhance clinical outcomes and empower patients, as the most studies commonly neglect the more mundane challenges to be solved so that more people could embrace it, particularly, in Indian rural communities. The prices of such devices also continue to be a major drawback, as stated in the research conducted by (Zou *et al.*, 2024)and (Kapur *et al.*, 2023). Also, the sections of patient education and digital literacy should be addressed to release the complete potential of these technologies, which is implied by (James and Musah, 2025) and (Hosain *et al.*, 2024).

While the clinical and behavioural benefits of IoT biosensors in diabetes care are clear, there is still much work to be done in addressing the practical barriers to their widespread adoption. A study of (Hosain *et al.*, 2024), (Kapur *et al.*, 2023), (Zou *et al.*, 2024), and (James and Musah, 2025) all agree on the potential of IoT to improve patient outcomes and empower patients, but the challenges related to cost, accessibility, and digital literacy remain key areas for further research. The comparison of these studies underscores the need for a more holistic approach to IoT adoption that considers not only the technological advancements but also the societal factors that influence their effectiveness in real-world settings.

2.3 Challenges and Limitations of IoT Biosensors in India

The capabilities of the biosensors created based on IoT in healthcare and diabetes, more specifically, are transformative. Although they are rapidly popularising in India, a number of obstacles stand in their way, such as affordability, digital literacy levels, and infrastructure inequality, which are crucial to the successful implementation of IoT technologies into the healthcare system.

One of the problems is affordability. Most of the population in India consists of low-income groups; therefore, healthcare technologies such as continuous glucose monitors (CGMs) are not affordable. As (Kumar *et al.*, 2022) speak about the fact that such high-tech gadgets are not always affordable to the patients in resource-limited circumstances. The fact that the technology is too expensive, particularly in the case of diabetic patients living in rural communities, is also outlined by (Dave *et al.*, 2022). This is aggravated by the fact that subsidies or assistance from health schemes are lacking, thus the low-income groups cannot enjoy the features of such innovation. According to (Kalyan, 2025), unless the IoT biosensors in diabetes care become a part of a public-private partnership or there are Government subsidies on the devices, the solution will be underused, and other population groups deprived of the additional healthcare services as offered by biosensors will bridge the urban/rural gap in healthcare delivery in India.

Another challenge poses a digital literacy problem, especially in rural settings. Though urban India can access smartphones and the internet better, in rural India, the digital divide is huge, and the low-tech literacy and lack of internet access cannot enable the usage of the IoT-enabled healthcare devices. According to (Parihar *et al.*, 2023), the usage of IoT biosensors in most cases requires mobile software or cloud computing, which patients in rural areas might not have an advantage to because of digital illiteracy. This problem is further escalated by the inadequacy of proper training of patients, which compromises the success of such technologies. As (Sajjan *et al.*, 2025) have stressed that inadequate training facilities can make the patients either misuse or underutilise the devices, defeating the intended purpose of benefiting their health. According to (Kumar *et al.*, 2022), such gaps in digital literacy and how to overcome them require educational interventions to promote more effective IoT adoption.

Poor infrastructure in rural India is also a weakness that inhibits the application of IoT biosensors. The low-quality internet connection, unreliable electricity, and poor healthcare infrastructure in rural areas do not support IoT technology that presupposes a stable data transfer. IoT-based biosensors without a reliable internet connection to transmit the data to the health care system or the cloud are major players in these conditions. As (Parihar *et al.*, 2023) state further that these connectivity woes limit the possibility of successfully employing IoT in rural healthcare, where gadgets could play an eminent role in managing the situation with the disease.

Moreover, (Kalyan *et al.*, 2024) note that not all healthcare facilities in rural settings can have the infrastructure to accommodate the advanced IoT solutions. The available solutions to implement the IoT in most healthcare systems in rural India are not adequate to successfully integrate the IoT, and therefore, it is challenging to monitor the progress of chronic illnesses, such as diabetes, which need constant monitoring. This inequality in infrastructure widens the gap between urban and rural healthcare. The urban environment makes it easier to incorporate IoT devices because of improved internet connections, increased smartphone population, and developed structures in medical facilities (Khan *et al.*, 2022). Instead, rural locations tend to lag, and patients meet considerable difficulties related to access to and the usage of IoT technologies (Talreja *et al.*, 2024).

Infrastructure, digital literacy, and accessibility are among the key issues that have to be addressed to bring the IoT biosensors to the national level of India. Although the urban regions might be able to get access to these advancements more easily, in rural areas, there is a severe disparity between the populations. Policies, education, and the building of infrastructure will play a decisive role in addressing these issues and achieving equality in healthcare outcomes with the aid of IoT biosensors nationwide.

2.4 Digital Literacy and Awareness among Indian Diabetic Patients

One of the biggest challenges that stands in the way of the IoT-based biosensors implementation in diabetes management in India is the digital divide, where some people have no access in terms of digital literacy. As (Kesavadev *et al.*, 2021a) bring up the extremely poor digital gap between the two populations existing in rural and urban areas, and IoT gadgets, like continuous glucose monitoring frameworks, tend to be expensive on mobile applications and cloud innovation, which requires a minimum measure of computer literacy. It is possible to adopt in the urban centres, where smartphone penetration levels and internet connection speeds are high. Nevertheless, there are rural territories with poor access to smartphones and the internet, which makes it harder to utilise IoT biosensors.

According to (Kesavadev *et al.*, 2021a), despite the increasing popularity of digital health tools in urban India, rural patients deal with serious limitations caused by the lack of digital literacy. The majority of diabetic patients living in rural settings lack accessibility to health apps necessitated to connect to an IoT device, in that, they fail to use, download, or even install such apps. The older people make the situation even worse since they constitute a big percentage of diabetic patients. Such people are not usually conversant with smartphones and digital technology, and this forms a significant obstacle in making use of digital health technology.

On the contrary, it was discovered that diabetic patients were more digitally literate in urban Haryana (Gupta *et al.*, 2023). This increased their quality of life as they would be better able to manage their diabetes with the help of online health facilities. A study of (Gupta *et al.*, 2023) noticed that online health forums and information about self-management helped the patients in these regions to comply with their lifestyles and adhere to the medication they were taking. There is a possibility that such tools will contribute to self-efficacy, in particular in combination with digital literacy programs and support networks.

This is, however, not the case in rural India. According to (Debnath *et al.*, 2017), health literacy levels of older rural diabetic patients are significantly lower in comparison with those of urban patients. Most of these patients do not know efficient diabetes management practices and the absence of their digital literacy makes the issue even more crucial. Following (Pal *et al.*, 2020), younger patients with diabetes, particularly those with Type 1 diabetes, are more likely to be used to digital health companions, given that they are more used to smartphones and the internet. Conversely, traditional patients might not embrace the use of the IoT-based biosensors because they might be older patients who are not comfortable using new technologies.

Another essential point by (AshaRani *et al.*, 2021) consisted of highlighting the gap in eHealth adoption, with the more urban populations getting access to digital health services at a higher rate than the rural. Although rural patients show interest in IoT technology, insufficient access to digital technologies and the internet scares them away. Such digital illiteracy can be especially distressing, bringing about an underutilization or inappropriate utilisation of IoT biosensors, which ultimately makes health management an even bigger problem within such communities. As Choukou et al. (2022) emphasise that rural diabetic patients are more susceptible to healthcare-related misinformation, and this factor contributes to poor performance in the sphere of using digital health systems.

In order to overcome them, the research by (Debnath *et al.*, 2017) implies the digital education of older populations and rural patients to achieve health literacy. Those programs might be provided at community health stations or mobile health clinics and assist in closing the digital gap and making sure that diabetic patients will be able to use IoT biosensors properly. The third argument that (Gupta *et al.*, 2023) provide is that healthcare systems need to incorporate digital health education as a standard care that they provide to both urban and rural patients.

The discrepancy in the urban and rural population in terms of digital health literacy is predominant. The needs and requirements of IoT biosensor adoption are present in urban environments where people can more easily access digital technologies and the internet, thus managing diabetes better. Nevertheless, the rural populations, especially older and low-income patients, experience high barriers because of a low level of digital literacy, insufficient internet quality, and ineffective healthcare infrastructure. To ensure IoT biosensors do not fail to treat diabetes nationally, the digital divide between rural and urban India should be eliminated. As (Kesavadev *et al.*, 2021a) and (Debnath *et al.*, 2017) issue a challenge, having policy interventions to promote digital education among underserved groups to leverage the employment of IoT devices in managing diabetes.

Although the knowledge of and utilisation of biosensors of IoT are increasing in Indian urban areas, no level of preparation has been achieved in rural populations to take advantage of the same. An educational program addressing digital literacy, outreach, and infrastructure development, in general, is essential to the dissemination of IoT biosensors in diabetes care throughout India.

2.5 Socio-Economic and Cultural Barriers to Adoption

There are high socio-economic and cultural barriers associated with the use of IoT-based biosensors in India, especially the equality of access to such potentially life-changing technologies. There are also socio-economic and cultural beliefs that affect how much people will accept using digital health tools, which include IoT biosensors, especially when managing a chronic disease like diabetes.

Expectation of cultural beliefs on health and medicine may have a significant impact on the adoption of devices which are part of the IoT. Appreciation of folk medicine, and its accompanying focus on personal relationships in the context of health care, is still very strong in rural India, including Ayurveda as well as homoeopathic medicines. Such conventional approaches are strikingly different to the distant, soulless presence of IoT solutions. As it is observed by (Kalsoom *et al.*, 2025), patients living in such regions can be quite intolerant of IoT-enabled devices using self-monitoring and sharing personal information with healthcare providers.

Socio-economic and cultural acceptance is rather diverse, but urban India is more willing to take technological innovations. Urban populations, especially younger ones who grew up with smartphones and digital health-related apps, are less afraid of self-management models that are promoted by IoT. The rural populations, however, encounter technological and cultural roadblocks because they are not fluent in using their health tools digitally and are not necessarily accepting technology entering the field and ruining the human aspect of healthcare (Verdejo Espinosa *et al.*, 2021).

Alongside the cultural resistance, the utilisation of IoT biosensors is obstructed by socio-economic reasons as well. As (Goel and Vishnoi, 2023) write about income inequality and its effect on access to such later-era technologies as continuous glucose monitors (CGMs). The devices are still very costly to the low-income groups, particularly in rural settings, which is reiterated by (Kalyan *et al.*, 2024). Such communities have a high number of patients unable to access these diagnostic tools, restricting their potential accessibility to the IoT-based diabetes management, even though it may provide significant advantages.

A study of (Almansour *et al.*, 2023) also stresses that, in the case of low-income populations, healthcare technologies should be considered secondary due to the increasing importance of food, shelter, and education as basic needs. According to (Pervez *et al.*, 2024), this may be addressed with government support or collaborations of the public and the private sector in order to make the IoT devices less expensive. The lack of such measures will only keep the socio-economic chasm, and it will leave the majority, mostly rural and poor urban people, out of access to life-altering technologies.

Research comparing urban and rural areas demonstrates that there are sharp differences between the uses of IoT biosensors. The urban dwellers have a higher level of access to smartphones, the internet, and digital literacy, therefore, allowing a smoother usage of IoT technologies in their diabetes management practice. A study of (Gupta *et al.*, 2023) point out that the rural population, especially uneducated consumers, is failing to deal with digital illiteracy and the high costs of technology in healthcare. The adoption of new technologies by such communities is also less likely since the communities are also inclined to more traditional health beliefs.

The impediments to the uptake of IoT biosensors are especially high among low-income and rural demographics, who have a combination of financial and cultural hindrances to consider. Although people in cities potentially enjoy more access to digital health tools, it is also important to consider the integration of more citizens by tackling problems of income inequality, digital literacy, and cultural acceptance. There is a need for policy interventions like subsidies, digital health education and infrastructure enhancement to alleviate these barriers and facilitate equity of healthcare in India.

2.6 Adoption of IoT Devices in Indian Healthcare Systems

To encourage the use of IoT gadgets in health care, the Indian government launched the National Digital Health Mission (NDHM) in the year 2020. The NDHM tends to create an ecosystem of digital healthcare that takes IoT devices, such as biosensors, into healthcare systems. As (Al-Rawashdeh *et al.*, 2022) note that the NDHM enables health records to be digitised and interoperability between healthcare systems. Such a union has enabled interaction between IoT devices such as biosensors, digital records, and mobile applications. The mission aims to fill the underdeveloped status of medical care, especially in rural environments with no infrastructure, by spreading IoT-facilitated health solutions to more people.

Availability of IoT technologies has been more aggressive among the private sector in comparison to the governments. According to (Thyagaraj and Narayanan, 2021), the IoT-based monitoring systems that have been adopted by the private hospitals, particularly those in the urban regions, include continuous glucose monitoring and remote patient tracking. The adopted IoT technologies can be adopted more rapidly in the private sector due to the increased financial resources and better infrastructure, presenting fewer bureaucratic interventions. As pointed out by (Shrivastava *et al.*, 2022), the adoption of innovative healthcare solutions is more likely to occur in the case of private organisations as they are motivated out of competitiveness and customer satisfaction. This is compared to the case of the public sector, which is plagued with under-funding, bureaucracy, and absenteeism of technical capabilities that are also an impediment to IoT adoption.

Nevertheless, the adoption of IoT in the public sector is not balanced among the states despite the actions of the NDHM. As (Kumar *et al.*, 2025) note that the success rate of employing IoT-based chronic conditions solutions, such as diabetes, has been higher in urban centres, where the main problems lie in a lack of investments in healthcare provision and internet connectivity, as well as skills shortages. They claim that the ambitious design of the NDHM needs locally predicated measures to culminate due to the localised issues that hamper the implementation of the proposed design regarding rural health care. They embody developing the digital infrastructure and creating the ability to implement IoT in rural health care.

The usage of IoT devices in the private sector significantly outrun its use in the public area, especially in cities. According to (Almansour *et al.*, 2023)The privately owned medical establishments can be more flexible in terms of investing in new technologies, such as IoT health monitoring systems, which are then incorporated as part of their IT structure. Such integration enables more communication between patients and the staff in medical devices. On the other hand, the government sector is under pressure in the timely adoption of such technologies, since it does not have the required instruments and infrastructure, whereas government initiatives such as the NDHM are in place.

Structural barriers limit the adoption of IoT in the public sector, as it lacks funding and has underdeveloped healthcare systems, not to mention being reluctant towards change. Although (Al-Rawashdeh *et al.*, 2022) appreciate the effort of the NDHM, they also note that matters, such as data privacy, interoperability, and scalability, should be considered so that IoT solutions can be successfully implemented throughout the country. The less regulated, more profitable, and adaptable approach of the private sector allows it to rapidly adopt and expand the implication of IoT technologies, as opposed to the slower pace of adopting it by the government. This inconsistency demonstrates the importance of a more combined strategy between the public and the private healthcare systems to reduce barriers to the use of IoT in the field of public healthcare.

Nonetheless, some obstacles do exist in the public sector even after the advances of the NDHM, such as change resistance, infrastructural inadequacy, and budgetary limitation. The private sector has been more efficient in the use of IoT technologies, particularly in the urban areas where infrastructure is more established.

2.7 Research Gaps and Future Directions

The current literature on IoT-Enabled biosensors in diabetes care in India reveals several key gaps, particularly, in patient experience, socio-cultural factors, and user-centred design. While studies like (Kesavadev *et al.*, 2021b) and (Kalyan *et al.*, 2024) discuss the technological benefits of IoT in healthcare and puts them in the context of clinical outcomes and functionalities of the systems. However, pay less concern to the day to day activities in which patients interact with such technologies. This gap is important since patient experiences on self-monitoring, data interpretation, and interaction with the healthcare providers is not sufficiently investigated. For example, while (Hosain *et al.*, 2024) highlight the clinical benefits of IoT devices; but fail to mention the experience of the patients who use the equipment, and this experience may provide information about adherence and satisfaction levels. Socio-cultural elements such as in the rural places are also a challenge to the application of IoT-Enabled biosensors. As (Kalsoom *et al.*, 2025) and (Debnath *et al.*, 2017) highlight that digital health technologies are hampered by traditional medicine. Second, the user-centred design of the IoT-Enabled equipment should be given more attention, especially to older patients or those with lesser digital literacy level, as noted by (Zou *et al.*, 2024) and (Kapur *et al.*, 2023). Future study should be conducted on experience of patients, socio-cultural barriers and user-centred design using qualitative research with an aim to enhance accessibility and uptake of IoT-Enabled biosensors.

2.8 Conceptual Framework

The theoretical study framework consists of three generic constructs: input factors, process factors, and outcome factors that predict the use of IoT biosensors in diabetes management.

Input Factors: Demographic factors, digital literacy, and Socio-economic factors. They impact the use of devices by the patients.

Process Factors: Usage of technology, usability knowledge, and clinician interaction. Patient technology use and interaction act as mediators of the impact of input on outcome.

Outcome Indicators: Self-management of IoT devices, patient empowerment, and clinical results such as the regulation of blood glucose levels. They also serve as input or feedstock for improving patients' knowledge and belief in the use of IoT devices.

Key Concepts

Several key concepts drive this framework:

•Digital literacy: Patients' ability to use IoT devices effectively, which is crucial for their engagement and sustained use (Kesavadev et al., 2021a).

•Awareness: Knowledge of available IoT biosensors and their capabilities, affecting adoption rates (Farooq et al., 2023).

•Patient empowerment: The degree to which patients feel in control of their health through continuous monitoring and self-management (Al Omar et al., 2020).

•Barriers to adoption: Socio-economic and technological barriers such as cost, lack of infrastructure, and privacy concerns that prevent widespread IoT adoption.

The framework highlights the intersection of technology, user experience, and health outcomes and provides an entry point to understand patterns and limitations of adoption in the Indian diabetic patient population.

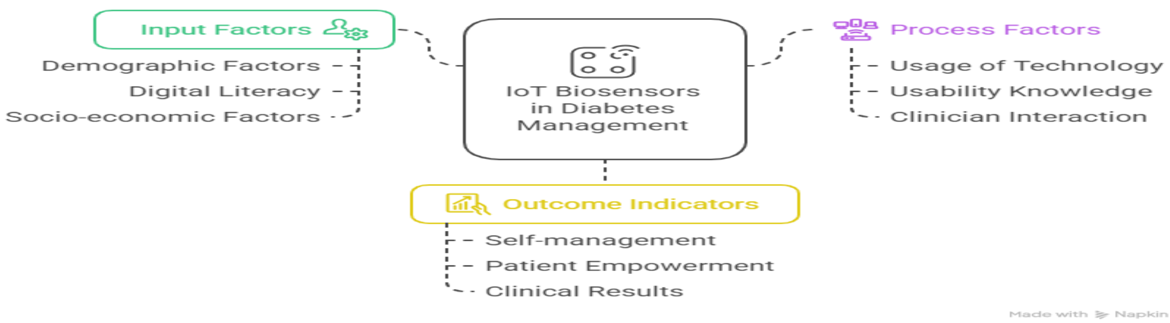

Figure 1: Conceptual Diagram Designed Using Napkin.ai

Figure 1 presents the conceptual framework highlights the intersection of technology, user experience, and health outcomes and provides an entry point to understand patterns and limitations of adoption in the Indian diabetic patient population.

While technology adoption by the healthcare sector has been studied academically, very little research has been done on the awareness, concern, and attitude of Indian diabetic patients towards IoT-based biosensors. This framework bridges the knowledge gap by interweaving patient data, technology adoption, and clinical implications.

CHAPTER 3

RESEARCH METHODOLOGY

3. Research Methodology

The chapter reveals the research methodology adopted to explore the adoption and utilisation of IoT-based biosensors in diabetes control among Indian patients. Methodology of research is the blueprint that lays down the data collection process, analysis, and interpretation to ensure the objectives of the dissertation are dealt with systematically and thoroughly. To provide a systematic foundation, the present chapter follows the Research Onion approach advocated by (Saunders, 2019), which provides a step-by-step guide to making methodological decisions.

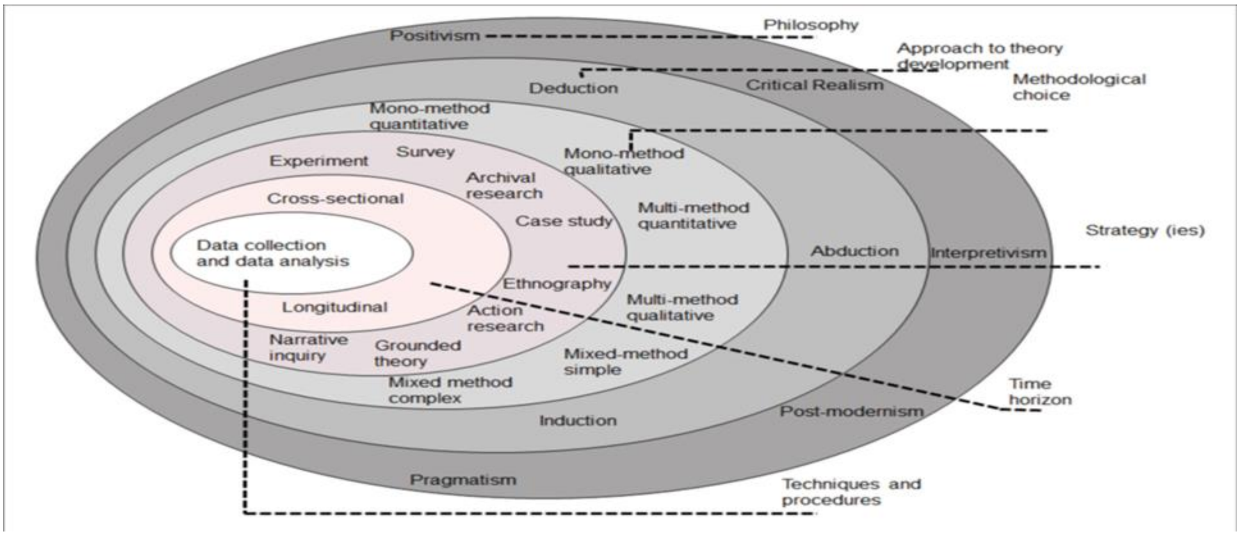

Figure 2: A Systematic Approach for Designing Research Methodology (Saunders, 2019)

Figure 2 shows the model of the Research Onion allows the researcher to specify key layers like research philosophy, approach, strategy, methodological decision, time horizon, and data collection and analysis methods. All these decisions are directly connected with the research objectives of the dissertation:

- To study the adoption of IoT-based biosensors among Indian diabetic patients.
- To determine the pros and cons of the use of biosensors from the perspective of the patient.
- To identify obstacles to adoption on the technological, economic, and social levels.
- To quantify the effect of digital literacy and awareness on biosensor adoption.

With a twin focus on quantifiable outcomes and patient perspectives, the research employs a pragmatist mixed-methods strategy, and both numerical patterns and personal experiences are considered. The following sections discuss each level of Saunders' Research Onion in this research.

3.1 Research Philosophy

Research philosophy is the set of assumptions about the generation of knowledge and the nature of reality (Saunders, 2019). For the sake of this research, pragmatism has been selected as the guiding philosophy. Pragmatism is based on the principle that the method should be chosen by the research question, and the emphasis is placed on outcomes and solutions (Dewey, 1938). Unlike positivism's concern for observable facts alone, or interpretivism's concern for subjective meaning, pragmatism allows the integration of the two.

Pragmatism, hence, offers the scope to synthesise quantitative survey research and qualitative inputs to produce pragmatic advice for healthcare professionals, policymakers, and technology developers.

Pragmatism has also been extensively used in eHealth adoption research, where both quantitative trends and user attitudes are of equal significance (Creswell, 2014). Adopting the philosophy, the study is open to any specific epistemological stance and maintains that methodological choices are made based on practical utility in resolving genuine, real-world health issues.

3.2 Research Approach

The research approach is the logic employed to link theory and data (Saunders, 2019). The study employs a mix of deductive and inductive logic.

Deductive reasoning: Descriptive analysis for known variables influencing digital health adoption, such as affordability, digital literacy, and socio-economic status. These are from accepted technology acceptance models as well as literature concerning healthcare technology adoption.

Inductive reasoning: Finding new insights through patients' feedback, particularly cultural inclination, infrastructure limitations, and the lived experience of managing diabetes with biosensors.

3.3 Research Strategy

Research design prescribes how the research should be conducted so that it can address the research questions. Some of the methods that could have been thought about in the Research Onion include experiments, case studies, ethnography, and grounded theory. However, in this study, a survey design is employed, with an online questionnaire being administered.

The reason why a survey is used is threefold:

Breadth of coverage: India already has over 77 million diabetic patients, distributed across urban and rural regions. Surveys allow us to reach an extensive, geographically diverse population.

Efficiency: Web surveys are time and cost-efficient, hence appropriate in the dissertation timeline.

Mixed-method integration: Surveys have the potential for integrating structured, closed-ended questions for quantitative analysis and open-ended questions for qualitative analysis.

In spite of the survey weaknesses towards self-report bias, surveys remain the most effective way to capture both adoption trends and patient attitudes at scale.

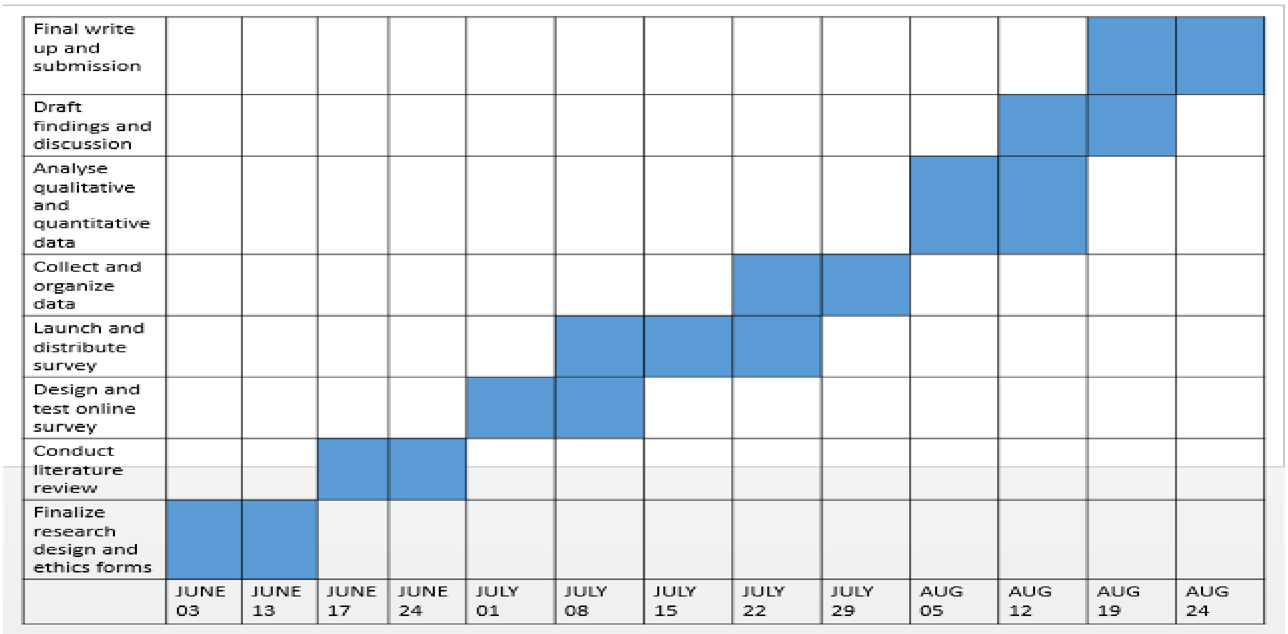

Figure 3: Dissertation Timeline

Figure 3 presents the Dissertation Timeline with the key steps and deadlines of the research project from Draft Research Proposal through to Dissertation Submission. The table employs correct dates and task durations to enable easy monitoring of progress.

3.4 Research Choice

This project employs a mixed-methods research option that integrates quantitative and qualitative data. Quantitative methods provide objective results of adoption rates, frequency of use, and satisfaction, whereas qualitative methods obtain subjective experience, i.e., usability problems, cultural problems, and perceived hindrances.

Mixed-methods designs are particularly suitable for healthcare technology research where both statistical patterns and human perception must be understood (Tashakkori and Teddlie, 2010).

Triangulation is used for the purposes of introducing reliability, with results from both methods cross-compared to help increase validity and reduce methodological bias.

3.5 Time Horizon

The time horizon defines whether the research examines data at one point in time or longitudinally. The dissertation assumes a cross-sectional time horizon because data were collected at one point in time. A longitudinal design would have given data on adoption over time, but it was not feasible under project constraints. Cross-sectional is still appropriate to collect the existing status of use of biosensors and attitudes of Indian diabetic patients.

3.6 Target Participants and Sampling

3.6.1 Target Population

The target population of the present study was Indian diabetic patients aged 18 or older who had used or had not used IoT-enabled glucose monitoring biosensors (i.e., Freestyle Liber, BeatO, or Bionime). Diabetes, both Type 1 and Type 2 is widely spread in India, and it is estimated that there are 77 million patients with diabetes in the country, which is why the population of diabetes patients in India is of interest, especially to service providers and organisations that deal with this type of care. Both the inclusion of only adults and the consideration of both type 1 and type 2 diabetes patients make them able to make their own decisions regarding healthcare, and the absorption of the differences in the uses of the IoT devices in the administration of the two types of diabetes provides a wider perspective on the subject. These participants will either have exposure or experience with IoT-enabled biosensors, which will give the information required to investigate their usability, perceived advantage, and barriers to adoption.

3.6.2 Sampling Strategy

This research will operate on a non-probability purposive sampling strategy. Such a method is reasonable because it will provide an opportunity to targetedly apply a sample of people with the corresponding experiences, i.e., people who have ever used or were exposed to IoT-based biosensors to manage diabetes (Palinkas *et al.*, 2015). Since the study aims to explore the experience of patients and how they interact with technology, purposive sampling will guarantee the inclusion of participants with prior experience of using the Tech and possessing the appropriate knowledge to share. Such an approach will allow taking into account a broad set of views of people with different degrees of digital literacy and socio-economic status, which is instrumental in understanding the obstacles to adoption in the Indian environment (Kesavadev *et al.*, 2021a).

3.6.3 Inclusion and Exclusion Criteria

Inclusion criteria will specify that participants must:

•Be Indian residents.

•Have a Type 1 or Type 2 diabetes diagnosis.

•Have used or been exposed to IoT biosensors (e.g., Freestyle Liber, BeatO, Bionime).

•Be aged 18 years or older.

Exclusion criteria will focus on individuals who:

•Do not have diabetes or have not used IoT biosensors.

•Are under 18 years of age, as they cannot provide informed consent.

3.6.4 Recruitment Methods

Participants were recruited through online channels such as diabetes support groups on Facebook, and What Sapp groups. Additionally, partnerships with NGOs and health portals focused on diabetes care may be explored for recruitment, ensuring access to participants from different regions and backgrounds. Online recruitment ensures convenience and scalability, allowing the survey to reach a large and diverse sample of participants.

3.6.5 Sample Size and Sampling Strategy

The study population were Indian diabetic patients, those of age 18 or above, who have used or have been exposed to the IoT-enabled glucose monitoring biosensors (e.g. Freestyle Liber, BeatO, or Bionime). The research methods consist of a non-probability purposive sampling approach to establish a sample characterised by people who have IoT biosensor experience. This strategy will help the chosen respondents bring the appropriate experience to the study to share their understanding of the practicality, pros, and challenges of embracing IoT devices in diabetes management. Using the purposive sampling method will enable inclusion of the digital illiterate and low-income category of participants, to get a better picture of the issues involved in embracing IoT technology among different groups.

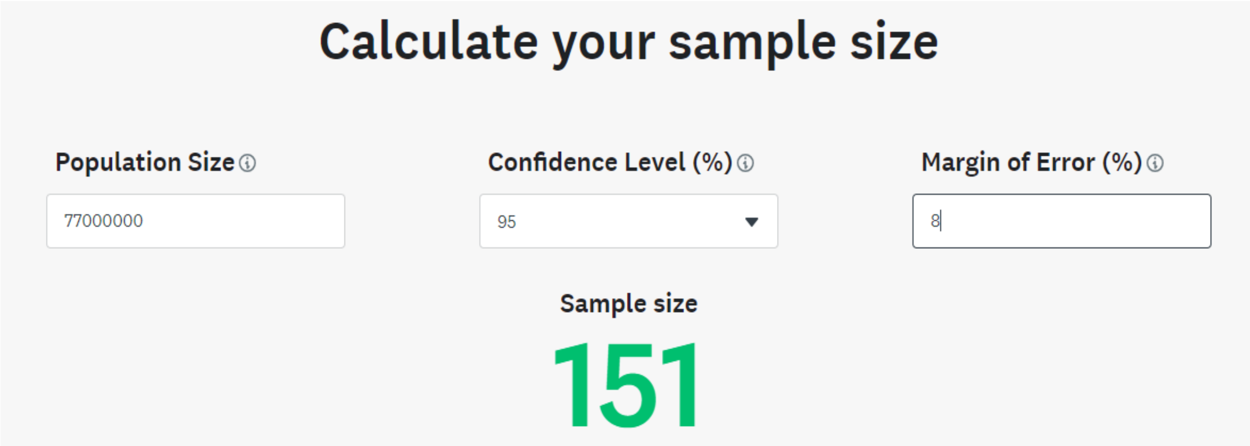

Figure 4: Sample size calculation via Survey Monkey

Figure 4 shows, it is estimated that there are approximately 77 million diabetic patients in India. The calculation of the sample size of 151 participants was done based on this population size with Survey Monkey at 95 % confidence level and 8 percent margin of error.

3.7 Ethical Considerations

3.7.1 Ethical Approval

The ethics clearance for this study was acquired through the utilisation of the Ethics Application Form and submitted to the review board of the institution. This review procedure will ensure that the study conforms to all the research ethical considerations and protection of the rights of participants in the study or ensure that the research work conforms to the institution where the study will be carried out and the ethical guidelines of the nation where the study will be carried out. The ethics committee will determine all of the processes, i.e., recruitment process, data gathering and analysis, to confirm that they are based on best research practices with channels involving human subjects (Bortz and Döring, 2013).

3.8 Data Analysis

3.8.1 Data Cleaning Process

The data cleaning process ensured the integrity and quality of the dataset. The process began by reviewing survey responses for completeness. Any surveys with more than 30% missing data were excluded to prevent biases. Duplicate entries were identified and removed to ensure that each participant contributed unique data. Outliers were flagged using statistical checks, particularly for age, with values outside the expected range (18-100 years) being flagged. These outliers were corrected where possible or excluded if no correction was feasible. Categorical variables such as Education Level and Age Group were standardised to ensure consistency and avoid discrepancies.

Missing data for variables like patient satisfaction and digital literacy were handled through mean imputation, allowing the retention of as much data as possible while maintaining the integrity of the analysis.

3.8.2 Descriptive Statistics Used

Descriptive statistics were employed to summarise and describe the main features of the data. Frequencies and percentages were calculated for categorical variables, such as age group, gender, place of residence, and education level, providing a clear picture of the demographic distribution. For example, 54% of respondents were aged between 18-30 years, and 52% of respondents were female, showing a balanced gender distribution. The age group of 18-30 years had the highest frequency, suggesting that younger participants are more comfortable with technology and more likely to adopt IoT biosensors for diabetes management. A Chi square test was conducted to examine the relationship between satisfaction levels with IoT-Enabled biosensors and residence type (Urban vs. Rural).

3.8.3 Quantitative Data Analysis

The quantitative survey data were analysed using Microsoft Excel. Descriptive statistics, including frequencies, percentages, and mean scores, were employed to quantify device usage prevalence, satisfaction levels, and the effect of IoT technology on patient self-management behaviour (Bryman, 2016). These statistical methods helped to determine patterns and trends in the data and provided valuable insights into how the adoption of IoT biosensors occurred and benefited various populations.

3.8.4 Qualitative Data Analysis

In the qualitative data, thematic analysis of the open responses to the questionnaires was used for analysis. Manual coding and sorting of the data were undertaken using Excel, so the common themes like cost, usability, privacy issues, and other issues with adopting technology could be identified. The coding entailed the reading of answers multiple times, noting the key details, and classifying the data into main themes. The process yielded extensive information regarding experiences and challenges that the participants faced in using and embracing IoT biosensors (Braun and Clarke, 2006).

3.8.5 Data Visualisation

Several visualisations were used to make the data easier to understand and interpret. Bar charts were used to display the frequency distributions of categorical variables, such as age group, gender, and place of residence. For instance, a bar chart demonstrated that 55% of respondents used the IoT biosensors daily, while others used them less frequently.

Pie charts were used to represent the percentage distributions of variables such as awareness of IoT biosensors and barriers to adoption. 50% of respondents identified cost as the most significant barrier, while 33% cited accessibility issues, especially in rural areas with weak internet connections.

A word cloud was generated from the open-ended qualitative responses, highlighting key themes such as cost, usability, and empowerment. The word cloud visually represented the most frequently mentioned words, with the font size of each word reflecting its frequency of mention.

3.8.6 Triangulation

To secure the reliability of the findings of the research, triangulation was utilised by integrating the results of the quantitative and qualitative data. The potential to cross-tabulate the information presented in figures (e.g., the frequency with which a biosensor was used and how content participants felt) with the narrative answers (e.g., what difficulties the patient faced and in what respects they would have benefited from change) facilitated a deeper understanding of patient experience with IoT biosensors. This was because, through the use of this mixed-method approach, a multi-dimensional view of the issue was achieved in a way that the research findings were not just statistically presented but also explained and supplemented with adequate data in the context of the actual life situations of the participants (Fetters *et al.*, 2013).

CHAPTER 4

FINDINGS AND ANALYSIS

4. Findings and Analysis

This chapter is aimed at serving as the presentation and analysis of the data that was obtained by the answers to the survey questionnaire and that should reveal the possibilities of utilising the IoT-enabled biosensors in diabetes management in India. This study will focus on answering the research questions by determining the effect of these devices on diabetes care, perception by the patients on their efficacy, and the gaps that hinder their uptake by patients. Interpreting the quantitative and qualitative data collected, this chapter attempts to provide a complete picture of what IoT biosensors do in the management of diabetes, which involves the experience they have, how satisfied the patients are, and the problems they face. Prior studies indicate that although these devices have a lot of potential in terms of improving patient care, adoption is usually dependent on cost, availability, and usability (Kesavadev *et al.*, 2021a); (Kanwar *et al.*, 2023). In this chapter, it will be provided with some ideas on how it is manifested in terms of the Indian context, especially in terms of differences in demographics.

4.1 Overview of the Chapter Structure

This chapter is structured as follows:

•The first section will focus on the quantitative findings, presenting an analysis of the survey data related to IoT biosensor usage frequency, patient satisfaction, and the key barriers to adoption.

•Following this, the qualitative findings will be explored, highlighting themes from the open-ended responses. These themes will provide a deeper understanding of patients' personal experiences with the devices, including usability, cost concerns, and perceived benefits.

•The third section will integrate the quantitative and qualitative findings, allowing for a more holistic interpretation of the results. This analysis will address how the findings align with the research objectives and compare them to existing literature.

•The chapter will conclude by discussing the implications of these findings, focusing on how they can inform future research and improve the adoption of IoT biosensors in diabetes care.

4.2 Transition

With this structure in mind, the following sections will begin by analysing the quantitative findings, starting with the presentation of the demographic characteristics and usage patterns of IoT biosensors among the surveyed participants.

4.3 Quantitative Analysis

4.3.1 Age

The demographics of the survey respondents were very diverse in age, gender, type of residence, and education levels, and the cross-sectional data could be considered representative of the wider demographic. In terms of age distribution, 54% of the respondents were aged between 18-30 years, with a significant percentage of 31% between 31-45 years, and still 13% of the respondents were aged between 46-60 years and 2% respondents were aged 61 and above. This demonstrates that the young population, especially the age group of 18 to 30, is the most frequent user of such gadgets, perhaps because they are more comfortable with technology or have better access to digital tools. The demographics of the respondents indicate that there is a growing trend to adopt IoT biosensors into the self-management practices of younger diabetic patients, which can have long-term applicability in diabetes management, provided they continue to incorporate IoT biosensors in their practices over the lifetime.

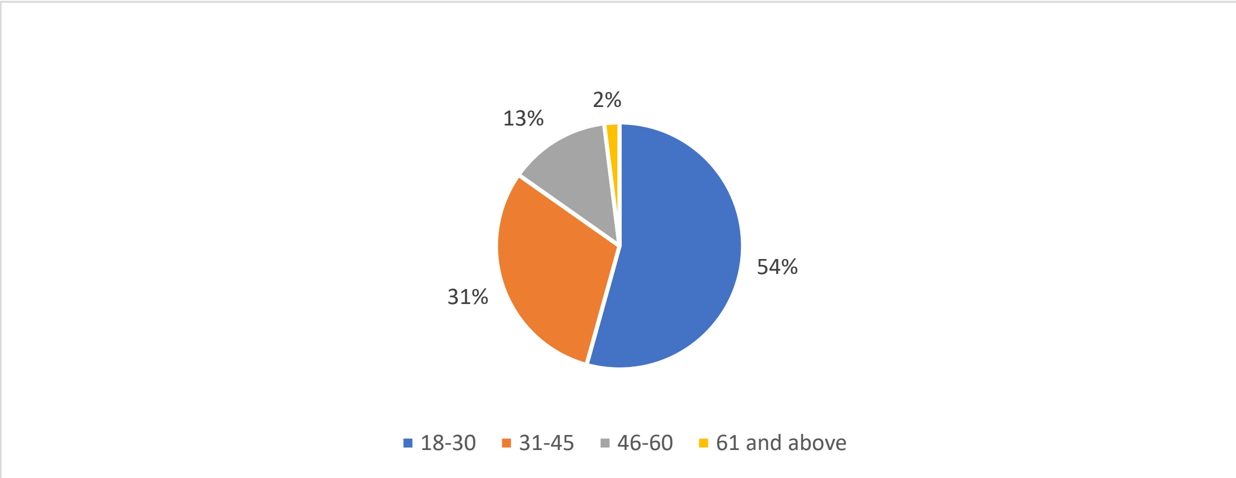

Figure 5: Distribution of respondents by age group

Figure 5 visually displays the age demographics of the participants. The majority (54%) were between 18-30 years old, followed by 31% between 31-45 years, 13% between 46-60 years, and 2% over 60 years.

4.3.2 Gender

On the issue of gender, the male and female respondents accounted for 46% and 52%, respectively, which provides a fairly distributed representation. Such a distribution enables a better perception of gender-specific encounters and experiences, which can shape the acquisition and application of these devices. The past research on the use of healthcare technologies has shown that gender may influence the desire and capability to implement them because of such factors as digital literacy, social support, and cultural norms (Kanwar *et al.*, 2023).

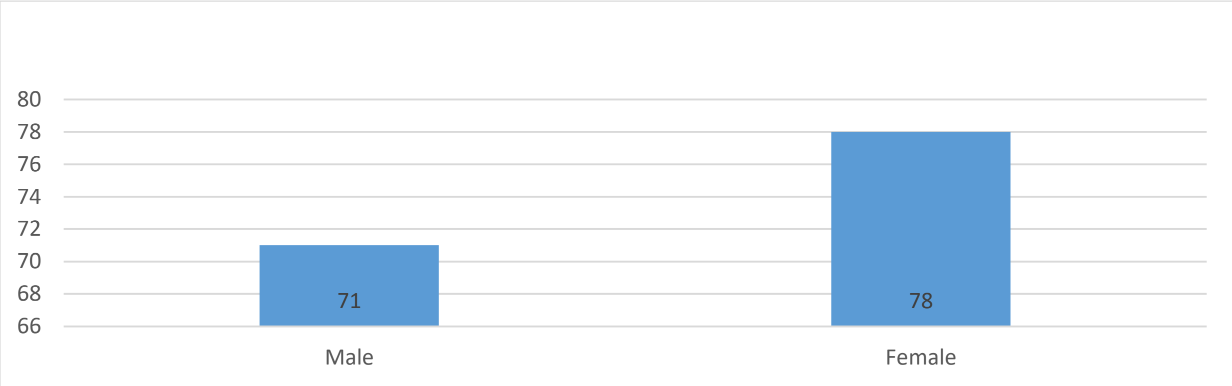

Figure 6: Gender distribution of respondents

Figure 6 shows a relatively balanced gender representation with 47% male and 51% female participants.

4.3.3 Residence

It indicated a marked urban bias in the residence of the participants, with 54% of them living in the urban areas, 29% in semi-urban areas, and a further 17% in rural regions. One does not need to be a genius to realise the growth of this disparity since the technological access rates in urban areas tend to be higher than in rural areas, where limited internet access, fewer smartphones, and insufficient healthcare facilities are the norm. The rural Indian community, as research in the past has indicated, still has a serious challenge in the implementation of digital health technologies because of infrastructural constraints (Sabharwal *et al.*, 2022).

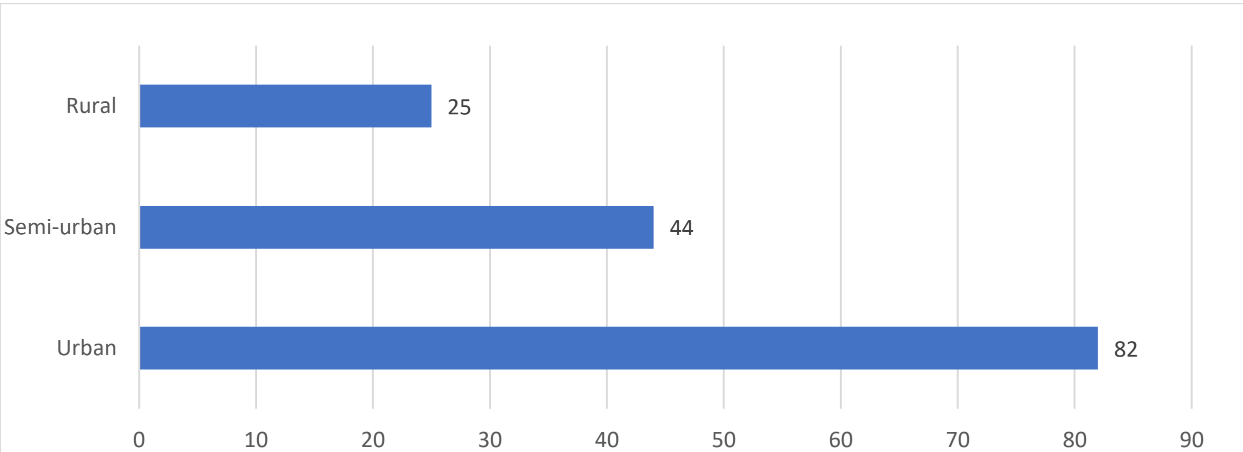

Figure 7: Respondent by place of residence

Figure 7 visually displays the data highlights the urban bias, with 54% of respondents living in urban areas, 29% in semi-urban and 17% in rural regions. This reflects the disparity in access to digital health technologies between urban and rural India.

4.3.4 Level of education

Educationally, the respondents of the survey were mainly educated, with the majority representing higher education (65%) (I.e. undergraduate or postgraduate degree), 25% for secondary education and 9% were only primary educated. The relatively high level of education of the respondents indicates that these people can have the digital literacy required to effectively use IoT devices, which is of primary importance when the successful implementation of healthcare technology is at stakeholders (Farooq *et al.*, 2023). The correlation between the level of education and digital literacy came out in the ease which the participants traversed the IoT biosensors and the app associated with them.

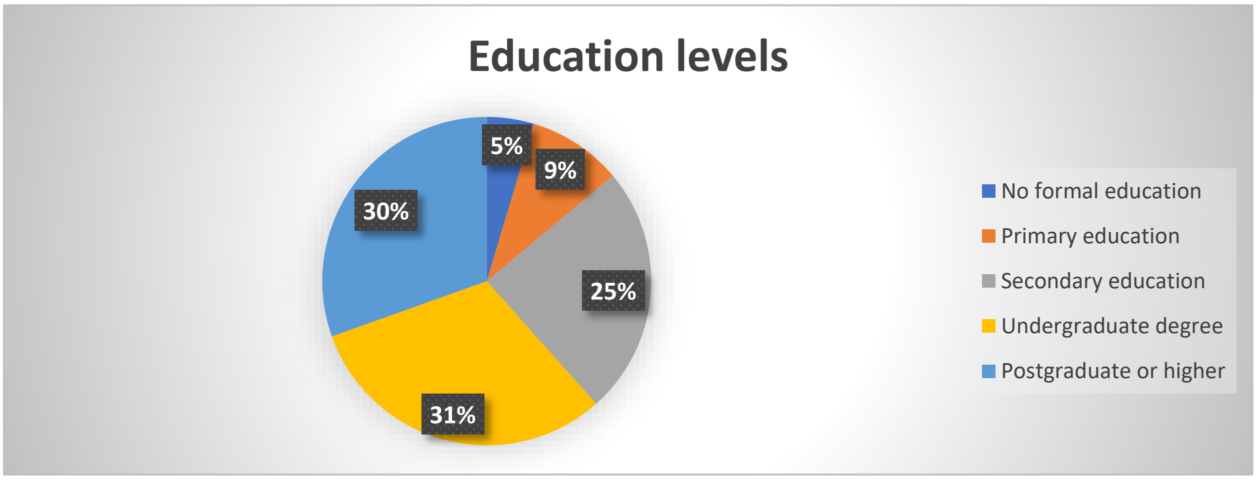

Figure 8: Educational background of respondents

Figure 8 shows that the most respondents (65%) had higher education, followed by 30% with secondary education, and 5% with only primary education.

4.4 Quantitative Findings

The closed-ended questions allow the quantitative collection of additional data that describes the specifics of using the services, the degree of satisfaction, and restrictions to adopting the services of IoT biosensors. Of the respondents, 151, 55 % used the IoT biosensors daily, and 35% used it three or fewer times per week, which is suggestive that the device is a part of the daily routine in managing diabetes of a significant number of patients. Still, another 32% of respondents referred to using the biosensor several times a week, which once again supports the notion that the device is essential in their lives. Nevertheless, 13 % have a less frequent use of the device, and this shows that although most may be dependent on it on an everyday basis, there remains a segment of the demographics where the device is not as important in their daily use.

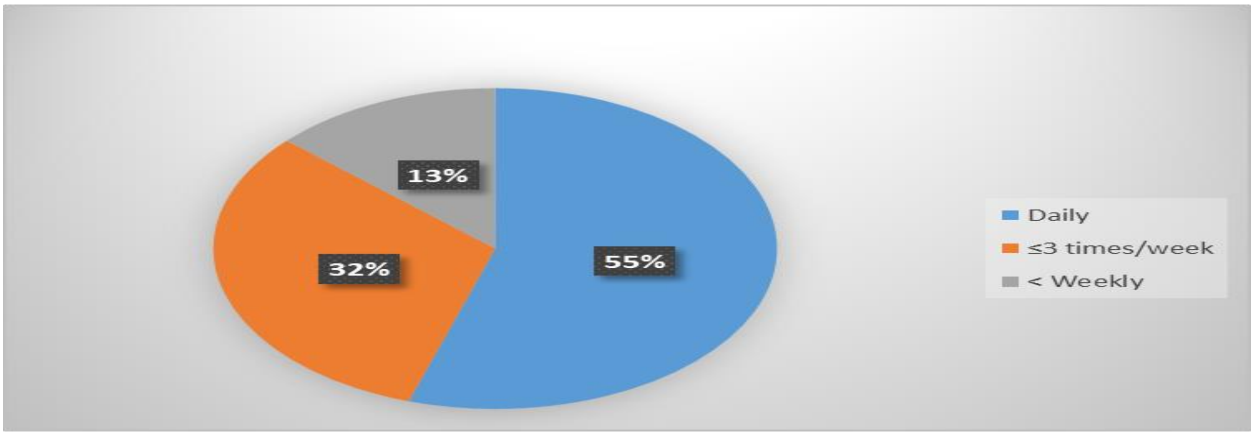

Figure 9: Frequency of IoT-Biosensor usage

Figure 9 shows that 55% of respondents used the biosensors daily, while 32% used them three or fewer times per week, indicating that the devices are essential for diabetes management for a significant number of users.

4.4.1 Patient satisfaction with IoT-Enabled Biosensor

Regarding patient satisfaction, the data shows the satisfaction of 87.57 % of the participants were satisfied and very satisfied with the IoT biosensors. Such high levels of satisfaction relate to the benefits perceived with the use of these devices, as they mean better glucose control, better decision-making, and fewer finger pricks. Nevertheless, less than one-fifth of the respondents were indifferent, and 1% dissatisfied with the gadgets. The main issues that may be defined as the common complaints of the over-satisfied group were connected with the problems of accuracy, battery life, as well as the complexity of the app’s interface, which people found difficult to use. Such an observation is consistent with the existing body of literature noting the importance of usability and device reliability as determinants of the success of digital health interventions (Mishra et al., 2024).

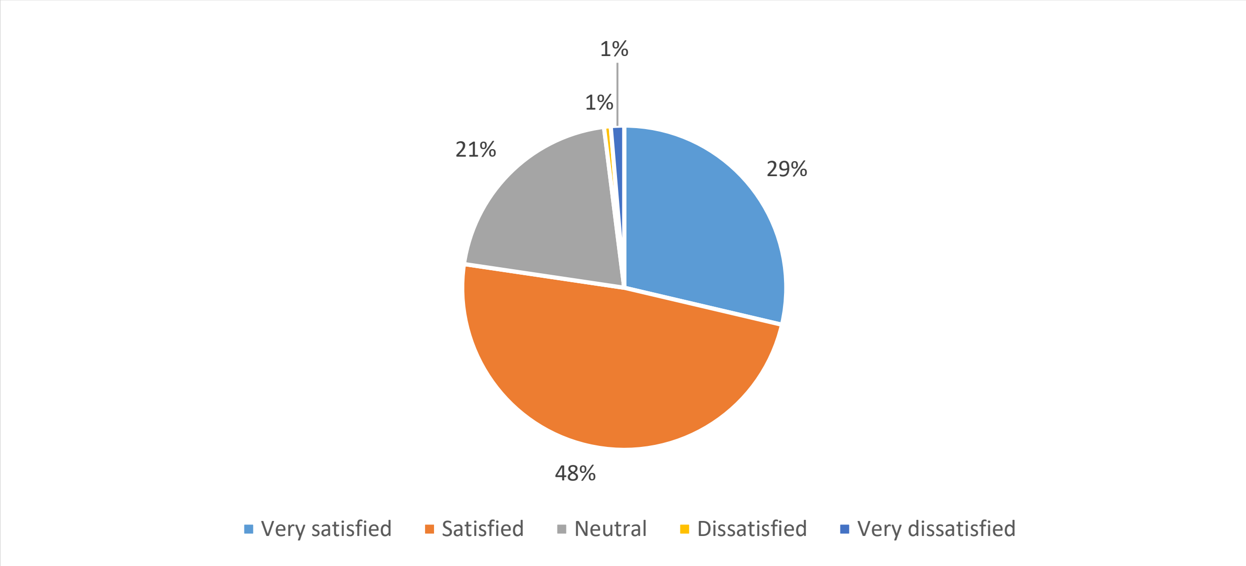

Figure 10: Patient satisfaction with IoT-Biosensor

Figure 10 pie chart shows that the satisfaction level was high, with 87.57% of participants reporting being satisfied or very satisfied with the devices.

4.4.2 Awareness and Digital Literacy Levels of Respondents

The statistics regarding the awareness and digital literacy indicate that 80% of the respondents have heard about the existence of IoT biosensors, and 65 % of the participants have stated that they feel sufficiently digitally literate to make use of the machines in question. Nevertheless, 35% reported difficulties, especially in the division of gadgets and data interpretation, which means that they should be more practical and simpler, especially in elderly patients or those with little technological knowledge.

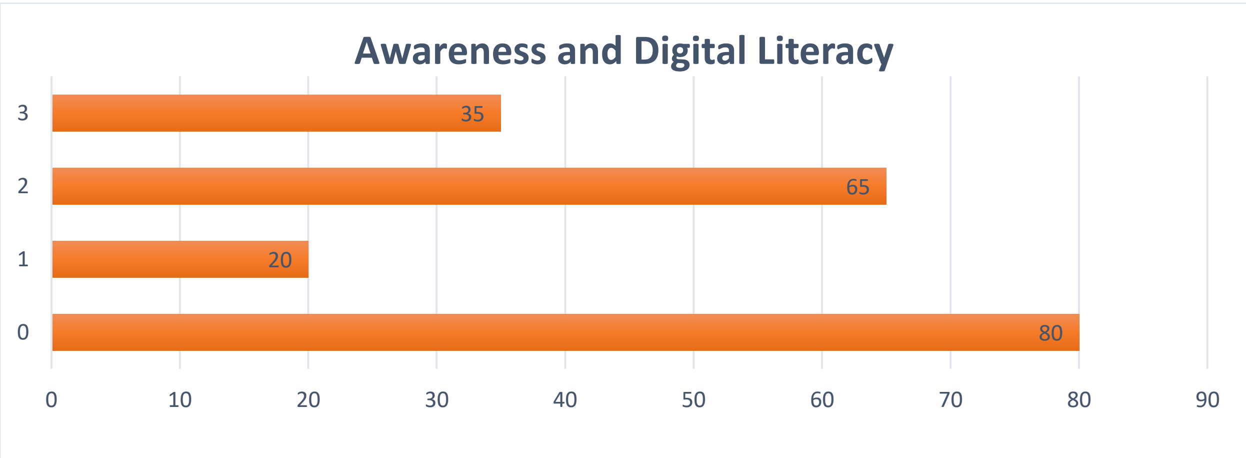

Figure 11: Awareness and Digital Literacy

Figure 11 shows that 80% of respondents had heard about the biosensor, 65% felt digitally literate to use them, 35% still faced difficulties, and 20% were not aware of IoT biosensors.

4.4.3 Barriers to Adoption

Responding to the question concerning the obstacles to adoption, the largest part (50% of respondents) mentioned the cost aspect as the greatest barrier. The same observation is true in previous literature that emphasised the aspect of cost as the major impediment to the use of IoT devices, especially in low-income countries (Kesavadev *et al.*, 2021a). Moreover, one-third of the participants cited acute problems of accessibility, especially in rural settings, where the internet connection is very weak. Also, 20% brought the problem of data privacy to the conversation, stating that the security of such devices should be strengthened so that they can safeguard personal health-related data.

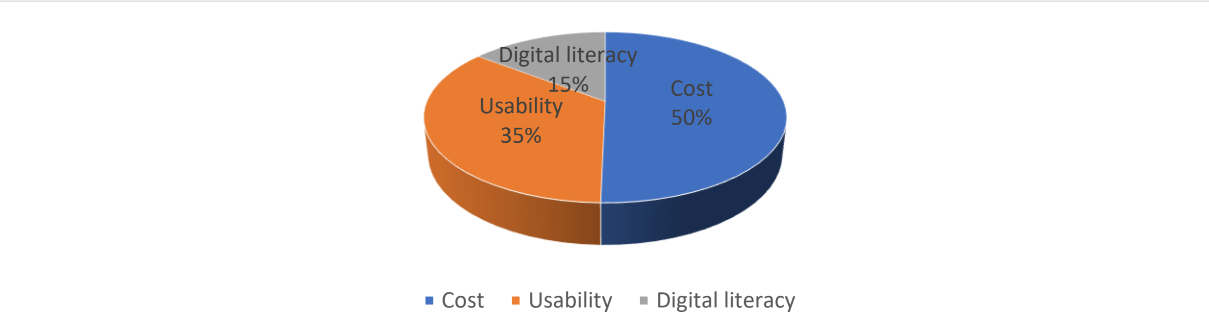

Figure 12: Barriers to adoption of IoT-Enabled Biosensors

Figure 12 shows that the primary barrier identified was cost, cited by 50% of participants. Other barriers included usability issues, particularly in rural areas, and concerns about digital literacy.

Satisfaction with IoT Biosensors by Residence Type

To examine how the type of residence (urban and rural) affected the satisfaction of IoT-enabled biosensors, we performed a Chi-square test of independence. This has been done to determine the influence of the level of digital literacy, the accessible infrastructure and socio-economic conditions on the use and perceived efficiency of the biosensors, since these parameters are likely to vary considerably between the urban and the rural population.

Chi-Square Test Methodology

The Chi-square test was applied to test the following hypotheses:

- Null Hypothesis (H_0): There is no significant difference in satisfaction levels between urban and rural respondents.
- Alternative Hypothesis (H_1): There is a significant difference in satisfaction levels between urban and rural respondents.

The data was categorized into four satisfaction levels: Significantly Improved Control, Somewhat Improved Control, No Change, and Not Sure. The expected frequencies were calculated assuming there is no relationship between residence and satisfaction, and are displayed in the table below:

Satisfaction Level	**Urban (Expected)**	**Rural (Expected)**
Significantly Improved Control	1.24	3.76
Somewhat Improved Control	2.73	8.27
No Change	12.88	39.12
Not Sure	11.15	33.85

Table 1: Expected Frequencies of Satisfaction Levels by Residence

Table 1 shows that he Chi-square statistic was found to be 8.19, and the p-value associated with the test was 0.042. Since the p-value is less than the significance level of 0.05, the null hypothesis is rejected, indicating a significant difference in satisfaction between urban and rural respondents.

Interpretation of Results

The results of the Chi-square test reveal that satisfaction with the IoT biosensors significantly varies between urban and rural populations. Specifically, rural respondents reported lower satisfaction, which may be attributed to several factors:

- Limited access to technology (e.g., poor internet connectivity),
- Lower levels of digital literacy, and
- Socio-economic barriers that hinder effective use and adoption of digital health technologies.

However, those with access to smartphones with stable internet connections and those with better and higher levels of di-digital literacy in the urban centres in the country rated the biosensor devices as more satisfying.

The findings highlight the need to work towards solving the adoption impediments in the rural settings. Solutions, which can help close the divide, include infrastructure projects, specialized low-tech literacy training, and government subsidies of IoT-enabled devices.

4.4.4 Analysis of Results

The findings demonstrate that diabetic patients, especially those living in urban regions, find great acceptance of biosensors related to IoT. The contentment rates are very high, showing how effective the devices have been on glucose management. Nevertheless, the financial aspect is likely to be a sizeable hindrance, particularly in disadvantaged environments such as in the countryside or low-income populations, where technology is not present. In addition, the usability concerns raised by certain participants point to the fact that the technology, despite all its positive aspects, has considerable gaps in user experience that are to be minimised, particularly in terms of patients with lower levels of digital literacy or those who are not experienced users of smart devices. These results are supported by other research stating that to implement IoT technologies in the healthcare system and make it successful, researchers should enhance affordability, accessibility, and usability (Sabharwal *et al.*, 2022).

4.5 Qualitative Data Analysis

4.5.1 Thematic Categories

In the context of the open-ended responses, a number of strong themes were identified, which helped to understand a wide variety of experiences and views of the respondents. The intended key themes that have been identified are usability, cost issues, and patient empowerment/ self-management. These themes contribute to the overall understanding of the effects of IoT biosensors on diabetes management and clarify why not all their patients are equally satisfied when using the gadgets.

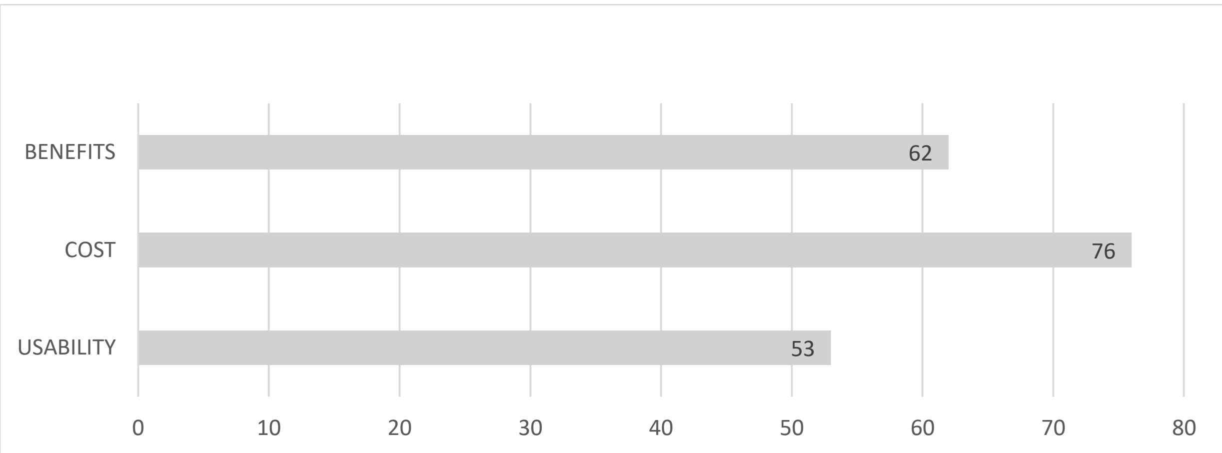

Figure 13: key themes of usability, cost issues and patient empowerment

Figure 13 has been identified are usability, cost issues, and patient empowerment/ self-management

4.5.2 Usability

The question of usability was the theme that was frequently referred to by the respondents. Most respondents mentioned that IoT biosensors aided them in the management of their glucose levels, yet they still experienced difficulties in using them. There was frequent trouble with the user interface and the interpretation of the data. This recalls the need to simplify the interface of the devices to make sure that any type of user (independent of their digital literacy level) is capable of operating the biosensors adequately.

4.5.3 Cost

Another important theme that came out of the qualitative data concerned cost. Other participants were worried about the cost of the devices, especially those with low-income status. The same theme prevailed in the quantitative data, where half of the respondents cited cost as the main inhibitor to the adoption of IoT biosensors. The substantial cost of the gadgets does not favour easy utilisation of the gadgets among individuals, especially in rural or poor regions. This is a critical challenge to the widespread use of these devices, particularly in low-resource environments where it is currently hard to get the devices due to a lack of affordability.

4.5.4 Patient empowerment

The patient empowerment theme was also a major feature of the qualitative results. A set of individuals stated that the IoT biosensors put them in control of diabetes management. The possibility of monitoring the glucose level and making the appropriate decision using real-time data in order to make adequate changes made them feel more engaged in their medical treatment. It is the same sentiment articulated by a few other people, and thus the empowering use of these devices in facilitating self-management and patient self-direction.

4.6 Word cloud

A word cloud was formulated to make a visual representation of the major themes and lessons that can be learnt through the qualitative answers. This word cloud illustrates those words that are mentioned the most in answers: cost, usability, empowerment, and battery life. The font size of the individual words in the word cloud is related to the number of times that word was mentioned in answers, thus giving the user a clear picture of the themes that have emerged during data. The cloud image is an asset to summarise key issues and advantages that people connect to IoT-biosensors.

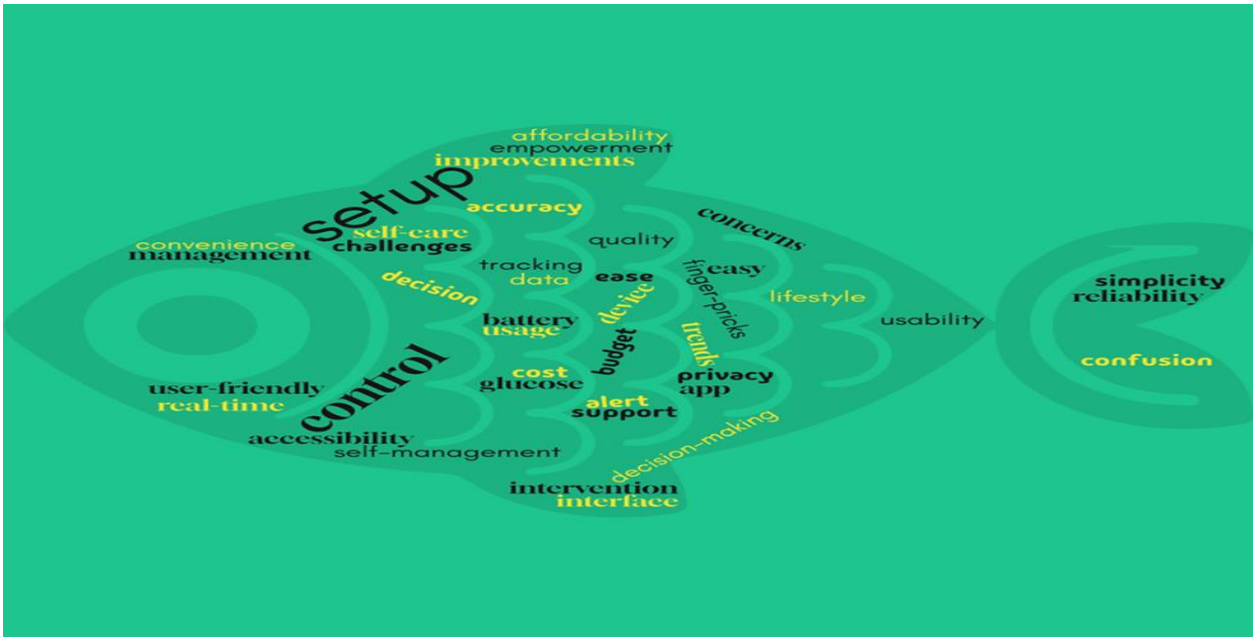

Figure 14: Word Cloud

Figure 14 presents a word cloud, which was created from qualitative responses, highlighting the most frequently mentioned themes.

4.7 Analysis of Results

The quantitative information is heavily supplemented by the qualitative information that significantly elaborates on why the trends indicate the survey. As an example, whereas quantitative data suggested that the satisfaction rates were at 70% as prescribed by the participants in terms of their IoT biosensors, it was observed that the qualitative data indicated that the issues of usability and cost were major factors that led to such satisfaction rates. The roles of digital literacy in determining how the devices would be usable are reflected by the responses given by the participants, where those with better degrees of digital literacy reported fewer problems using the devices.

In addition, there was evidence of the urban and rural participants being different, as the responses to the analysis showed. The level of satisfaction and technical problems was generally lower in rural users, although they reported having some challenges, including the lack of an efficient internet connection, with a low level of digital literacy. Such disparities were present not only in the quantitative data, where the participants in the rural arm indicated a lower level of satisfaction, but also in the qualitative responses, where poor internet connection and inability to operate the app were mentioned by the rural participants numerous times. The results also indicate that although the perceived benefits driven by the IoT Biosensors, including the factors of enhanced self-management and empowerment, are well recognised, cost is one of the major impediments to the expanded uptake. This obstacle is in line with the quantitative element: 50 % of participants reported cost as a major barrier. By either reducing the prices of IoT biosensors or subsidising these systems, this problem may be addressed, resulting in an increase in their penetration in the population, especially in low-income and rural areas.

4.8 Integration of Quantitative and Qualitative Data

4.8.1Triangulation

Triangulation is seen as a combination of the two data, that is, quantitative and qualitative, as a way of attaining a specific understanding of the research issue. In the study, triangulation becomes essential in the process of filling the gap between the quantitative data that one can acquire through the survey and the rich and descriptive feedback that one can receive by means of the open-ended responses.

The quantitative variables, the degree of satisfaction among patients with the devices and how often they use them, and obstacles to their use give a statistical picture of the trends and patterns of IoT biosensors usage. On the contrary, the qualitative data provides a further understanding of the why of these trends and focuses on personal emergencies, seeing them as internalising the devices have on self-management practices of the patient. Combining such two kinds of data can lead us to a more comprehensive conclusion of the aspects that contribute to the success of IoT biosensors in the context of diabetes care.

The Table 2 shows, the quantitative results demonstrate that 70% of the respondents were pleased with the devices, whereas the qualitative results indicate that the degrees of satisfaction were significantly affected by the usability problems and price-related matters. The nuance can be introduced by triangulation of these findings: the devices are broadly satisfying the patients, but usability difficulties and the cost limit the adoption to be much broader and even more consistent. The approach improves the accuracy of the results and makes the interpretation of data more substantial.

Theme/Indicator	Quantitative Result	Qualitative Evidence	Interpretation
Cost barrier	76 respondents (50.3%)	28 quotes explicitly citing high cost or subscription fees	Cost is the leading adoption barrier, restricting use in rural and low-income groups.
Usability issues	53 respondents (35.1%)	21 quotes on confusing interface, navigation difficulty	Usability challenges reduce frequency of use, especially among older users.
Empowerment	Satisfaction: 70.2%	62 empowerment quotes (decision-making, independence)	Perceived benefits offset some barriers, maintaining high satisfaction.
Accuracy	Not directly measured in survey	48 quotes citing accurate readings	Technical reliability is a strong driver of satisfaction.

Table 2: Triangulation of qualitative and quantitative findings on IoT-Enabled Biosensor Adoption

4.8.2 Visuals

To summarise the integration of the quantitative and qualitative data, a table can be used to present the similarities and differences between the two data sets. Below is an example summary table that compares the key findings from both the quantitative and qualitative analyses:

Theme	Quantitative Findings	Qualitative Insights
Satisfaction with Device	**70%** of participants are satisfied with the devices.	Many respondents reported improved **self-care** and **glucose control** but highlighted **usability** and **cost issues**.

Theme	Quantitative Findings	Qualitative Insights
Cost Concerns	**50%** of participants identified **cost** as a major barrier.	Numerous respondents expressed that the devices were **too expensive**, preventing regular use.
Usability	**35%** reported difficulties in using the devices.	Common issues included **app interface confusion** and **difficulty in setting up the devices**.
Patient Empowerment	**55%** of participants feel more in control of their diabetes.	Many users felt **empowered** by having **real-time glucose data** and the ability to **make informed decisions**.
Digital Literacy	**65%** of participants reported being digitally literate enough to use the devices.	Several participants, particularly older or rural users, faced difficulties with **data interpretation** and **device setup**.

Table 3: Comparison of Quantitative Findings and Qualitative Insights on IoT Biosensor Usage

Table 3 shows that the combination of the quantitative and qualitative results provides a complete testament to the reasons that may affect a positive attitude to and satisfaction with the need and desire aspect of IoT biosensors in diabetes management. Though the quantitative data gives the general impression of a high level of satisfaction, the qualitative answers help to find out some significant nuances, like the fact of usability problems and the costs that are currently preventing the wider use. Triangulating the two data sets means we can have a more in-depth understanding of how the factors affecting patient experiences with usability, cost, and digital literacy relate, enabling us to make our recommendations on the effectiveness and accessibility of the technology. Corrections on usability issues, more emphasis on digital literacy programs and methods to make it affordable are areas that might encompass great success in the use of these devices, especially in the low-resource environment. Such integrated findings can contribute to consistency with the literature on the topic and provide a more comprehensive way of perceiving issues and opportunities that surround the use of IoT biosensors in managing diabetes (Kanwar et al., 2023); (Sabharwal et al., 2022).

4.9 Explanation & Interpretation of Findings in Relation to Literature

4.9.1 Demographic trends & digital readiness

The demographic data analysis has shown that the most popular age group was 18-45 (the majority of the respondents fell in it), the gender factor was almost equal, and it was mostly city dwellers. This profile represents a demographic group that is characterised by being more digitally ready, especially in their comfort level with smartphone apps and connected technologies. The great distinctiveness of the younger and middle-aged adult population is consistent with the previous body of evidence, as these populations demonstrate higher rates of IoT-based health technology adoption due to being a more technologically literate population and demonstrating an attitude of taking proactive approaches to managing their health. Such a skew towards living in the city correlates with the benefits of infrastructure like access to a steady internet and to technical assistance.

The inference is that present-day adoption of IoT-enabled biosensors remains skewed towards the segment of the population who have the infrastructural and cognitive capacity to adopt and incorporate the devices into everyday care. This connection is also reinforced by the qualitative results: younger people frequently mentioned that they were confident in using device interfaces, but older people expressed fear, which proves the hypothesis that age affects perceived as well as actual digital preparedness.

4.9.2 Usage patterns

The scale on quantitative findings was that daily use of the device occurred most frequently among the age bracket of 18-45, with a decreasing trend in the age brackets. This is analogous to the existing studies on international engagement that have recorded equivalent age-related gradients in these wearable gadget usages on relatively high drivers of motivation and perceived significance, and ease of use. The ratio of the digital-literate demographics presents concentrated users as the potential daily users compared to other demographics, meaning user demographics will have and retain most of the users, hence adopting more continuously as a form of behaviour, including monitoring.

Qualitatively, participants with an overall use that was described daily insisted that the biosensor provided peace of mind and guided food or medication changes. This is akin to device engagement models, which highlight the importance of the "perceived utility" as a force behind repeat use. The quantitative frequencies, qualitative wrapping stories, and the triangulation of the two provide evidence that users can remain engaged when they perceive a visible connection between readings and actionable life choices.

4.9.3 Satisfaction levels

The percentages of satisfaction were at a high level, and the greatest number of responses belonged to the categories of Very satisfied and satisfied. These findings are widely applicable to (Kesavadev *et al.*, 2021a)who report high user satisfaction with continuous glucose monitoring devices, where the perceived accuracy is high and the requirements to use them are relatively non-invasive. In the same way, (Sabharwal *et al.*, 2022) stated satisfaction had a strong association with data reliability, output and readability.

Nevertheless, the absence of a statistically significant correlation between satisfaction and education level can indicate that although the level of education affects digital readiness, the level of education is not a guarantee of the emotional or practical satisfaction with device performance. This is in contrast with (Sabharwal *et al.*, 2022) but to a small degree, because higher education was always a predictor of satisfaction. A possible reason is that the ease of use of the device, as well as personal health priorities may have a more significant stimulating effect on satisfaction than formal education, in the given sample. Qualitative elucidations also facilitate putting context to these findings: texts on the topic of real-time alerts and trend tracking were appreciated by the participants, with some of them revealing that the features allowed them to feel more at ease or less anxious. These reactions depict satisfaction as a complex phenomenon which combines instrumental satisfaction with emotional validation.

4.9.4 Barriers (Cost, Usability, Digital Literacy)

The superior barriers were costs, which were mentioned by over 50% of respondents, followed by usability glitches and digital literacy limitations. Such obstacles closely overlap with other studies in IoT health implementation around the world, most of which point to affordability as a major inhibiting factor, particularly in low- and middle-income settings (Kesavadev *et al.*, 2021a). This has been supported by qualitative evidence where the concerns relating to costs are usually associated with sensor replacement costs as opposed to purchasing the device itself.

The usability issues were mostly interface-related, the respondents mentioned confusing navigation, inconspicuous labelling or incompatibility with devices to apps. This reflects the conclusions of studies on the topic of usability, which point to the relative discouragement of the elderly or less digitally savvy by an overly complicated interface. The least cited obstacle to digital literacy was still an important adoption barrier in rural settings and among older participants, mirroring ideas in the literature about the role of the digital divide in healthcare technology uptake. The fact that the quantitative ranking and qualitative narratives converge makes the results more valid. Notably, there are also discrepancies in the fact that, to some extent, high-usage individuals also reported feeling frustrated with usability; hence, the presence of barriers may not always indicate non-adoption but rather have implications on the longevity of satisfaction and engagement.

4.10 Limitations of the Analysis

There are a number of methodological and analytical limitations to this analysis that have to be considered when considering the findings.

First, a modest sample of n = 151 constrains the statistical power of some subgroup analyses and constrains the circle of application of findings to the greater population of Indian users of IoT biosensors. Although purposive recruitment made the study relevant to the research topic, the demographic composition that will be drawn might not be significant enough to capture every age, education and geographical segment. This blind is further enhanced by the fact that there was a possible bias of self-selection wherein the highly motivated former subjects, or those who were generally favourable towards technology-based diabetes management, were more prone to joining the study.

Quantitatively, the investigation was limited because of the few variables provided in the survey presented. Other important contextual factors, including an elaborate description of socioeconomic status or comorbidity profile, were not obtained, which would have enriched the interpretation of usage pattern and level of satisfaction. Moreover, established self-report data dependence gives rise to recall bias and the probability of socially desirable answering.

To a degree, there is always subjectivity in the coding decisions that have been made in the qualitative component, although the audit trail and checks between the coders were applied to improve reliability. My research interviews offered some short responses to open-ended questions or did not provide enough detail, which restricted the thematic exploration of that response.

Analytically, some of the small subgroups' sizes (e.g., only primary education respondents, rural high-frequency users) decreased the possibility of strong statistical testing. As an example, other chi-square tests had cell frequencies that were less than the prescribed guidelines and thus necessitated more regressive interpretation or different statistical tests.

4.11 Recommendations

Policy: Since the most relevant inhibitor was the cost (50.3 per cent), there is the possibility of government and non-profit programmes offering subsidies to purchase the device as well as sensor replacements so that cost competitiveness is enhanced, particularly among the rural communities.

Design: The 35.1 percent of persons who reported usability issues signify that attention to UI/UX requires targeted improvements to include simplified navigation, larger icons, and labelling. Such modifications would take care of both the qualitative grievances as well as the quantitative data relating usability to the degree of satisfaction.

Industry: Manufacturers should form partnerships with healthcare providers for structured onboarding sessions. This would respond to the qualitative insight that many participants learned to use the device informally, leading to avoidable operational errors.

Research: Future research ought to combine clinical outcome measures (e.g., changes in HbA1c, complication rates) to consider the medical effects of using biosensors in addition to self-reported phrases. The limitation of the current study, its cross-sectional nature, could be overcome by longitudinal monitoring of the variations in the level of satisfaction, how often one uses it, and perceived barriers over a while. The recommendations directly address a given finding: the subsidisation of costs responds to the most reported barrier; the changes in UI/UX respond to the complaints on usability; provider collaboration corresponds to the training gaps; and expanding studies respond to the lack of clinical impact measures in the current dataset. These actions would improve the adoption and long-term use of diabetes-managing IoT-enabled biosensors.

CHAPTER 5

CONCLUSION

This dissertation aimed at investigating the adoption and experience of diabetic patients in India using IoT-driven biosensors: the adoption patterns, the benefits and challenges associated with its usage, and related socio-economic and cultural obstacles. The objective was to go beyond a mere clinical evaluation of these devices and shed some light on the patient angle, especially in a nation where access to healthcare and digital maturity is broadly varied between urban and rural regions. In the final chapter, the key findings presented in the paper are summarised relative to the research objectives, a statement on the limitations of the study is given, which is followed by recommendations to be made on future studies, practices, and policies.

5.1 Summary of Main Findings and Implications for Research Questions

The paper fulfilled its goals by looking at the case of application of biosensors like Freestyle Liber, BeatO biosensor, and Bionime in the context of diabetic people in India. The results show that such devices are used the most by younger and urban respondents, who are more digitally literate and more likely to afford an advanced healthcare technology. A majority (more than half) of the respondents declared daily use, which implies that the biosensor has become an inseparable component of self-management in this section of the population.

The advantages of the use of biosensors were universally recognised. Individuals appreciated the opportunities to observe glucose on a real-time basis, to spend less time on painful finger-prick blood test procedures, and to consequently make timely adjustments in treatments. Biosensors and smartphone coupling with alert systems also improved the confidence and adherence to self-care on the part of the patient. These merits could be seen in the high rates of satisfaction recorded, where more than eighty percent of the respondents were positive about their experience.

Meanwhile, there are a high level of obstacles that stand in the way of mass adoption. The highest concern raised was cost, with half of the respondents citing high prices of devices and subscriptions, which limited access to rural and low-income patients. Also, the level of digital literacy proved to be a decisive factor in successful use. Generally, online participants were more secure in handling technologies such as biosensors. Some rural participants and older adults, however, were unable to install apps, analyse data and troubleshoot technology-related problems. In addition, biosensor perception was also informed by cultural attitudes. Most of the respondents, particularly those located in farming areas, stated that they would have preferred doctor-led follow-up and were highly reluctant to adopt the self-directed monitoring model that IoT devices seemed to promote.

In summary, the study confirmed that IoT-enabled biosensors are effective tools for improving self-management and quality of life among diabetic patients. However, their adoption is heavily mediated by economic capacity, digital skills, and socio-cultural acceptance. These findings highlight the importance of linking technology development with contextual realities in order to achieve sustainable health innovation.

5.2 Summary of Differences between Findings and Literature

Urban vs. Rural Adoption

This study contradicted what was mentioned in past literature, as they primarily concentrated on discussing the clinical efficacy of the IoT technology devices, like the Freestyle Liber and BeatO devices, without discussing the socio-economic as well as infrastructural obstacles to the adoption of the devices at length (Mishra *et al.*, 2024). This paper drew a more critical urban-rural division whereby the rural, with a lower density of digital facilities and lower surrounding digital literacy demand, had a greater struggle as opposed to their urban counterparts. Such barriers are often underrated in the literature that emphasises more technical features, without paying much attention to the actual difficulties of accessibility (Kesavadev *et al.*, 2021a).

Patient-Centred Approach

This paper has highlighted the significance of a patient experience, paying attention to the ease of use of the IoT biosensors and their impact on self-management activities. As opposed to the literature, which mostly addresses the clinical outcome and technical features (Li *et al.*, 2024), this study took into account the role of user interface design, cultural resistance, and digital literacy in influencing the rates of adoption. In one case, rural patients were less likely to be willing to utilise digital health solutions because of a proclivity to traditional care methods (Gupta *et al.*, 2023). This patient-based approach allowed people to gain an idea of the lives of people who used this technology, and this group of people is hardly studied in the presented literature traditions, which have a more clinical view of the technology.

5.3 Recommendations

The results of this study suggest some recommendations that could be of use to various levels of stakeholders. Affordability is a major issue of concern to policymakers. The biosensor devices should also be subsidised by the Government programmes or national health initiatives such as the Ayushman Bharat Digital Mission. Development of digital infrastructure in the rural setting, especially internet access and stable supplies of electricity, will also prove crucial for biosensors in all environments to be functional and effective. There should also be awareness campaigns and culturally acceptable training programs that utilise local languages and reputed community health workers to address the scepticism and resistance to be overcome among populations that are less digitally literate.

One step that is significant step in the context of healthcare practitioners is the incorporation of data by the biosensors in clinical practice. To enable doctors and nurses to interpret the device outputs and educate patients to use them, they should also undergo training. Incorporating digital health education in the process of regular diabetes care would also give patients more freedom in terms of independent control over their condition. To the developers and stakeholders in the industry, there is an urgent need to design devices that are affordable and at the same time easy to operate. The simplification of interfaces, development of tiered pricing models, data security and privacy may lead to enhanced trust and accessibility of patients.

Lastly, to the researchers, the study reveals the necessity of longitudinal research studies where the long-term impact of long-term use of biosensors in patients is evaluated, as well as their effect on patient behaviour. The results could be compared across urban and rural communities as well as on a deeper qualitative level of investigating their cultural perceptions of self-monitoring. Investigations into the nature of user-centred design in low-resources situations would also be quite beneficial, so that in the future, developments are more inclusive and equitable.

5.5 Limitations and Contributions of the Research

Limitations

This study, like any others, was faced with a set of limitations that should be taken note of when passing judgments over the findings. The number of participants (n=151), although not very large, was significant enough to increase the study's generalizability to the overall number of diabetics in India. The approach to recruitment was mainly based on digital platforms, which, perhaps de facto caused a bias by excluding some patients who do not have access to the internet or digital literacy skills and, as a result, made the sample urban-oriented. Also, the research was considered cross-sectional, and only some experiences of the patients were reflected at one point in time. This was useful in understanding the present trends of adoption, but it could not make it possible to understand how perceptions and use change as time proceeds. Lastly, the fact that self-reported data is used adds the potential of recall bias and socially desirable answers. Such limitations do not undermine the worth of the study and emphasise the necessity of further studies that should increase its scope.

Contributions

Despite these limitations, the study contributes significantly to bridging the gap between clinical research and real-world patient experiences with IoT biosensors. By focusing on socio-cultural factors and economic barriers, this research provides a more comprehensive understanding of the challenges and opportunities of adopting IoT technologies in India. It also highlights the importance of contextualizing health technologies to suit the unique needs of Indian diabetic patients, particularly in rural areas.

5.6 Suggestions for Further Research

Additional research on the topic should be dedicated to longitudinal studies to evaluate the long-term outcomes of the IoT biosensors on the management of diabetes and patient outcomes. The ability to interpret how the continued use of these devices affects health indicators given an extended timeframe would be an eye-opener on how these devices can be employed to enhance care of chronic diseases in India. These studies may also analyse the loss rates of users and elements that may contribute to sustained use of IoT technologies.

The other potential direction to make future studies is on a comparative basis of different regions within India. These studies would assist in defining regional features in the adoption of IoT biosensors based on dissimilarities within the healthcare system, digital literacy, and socio-economic status. This type of research would give a more detailed insight into how local factors in the effectiveness of IoT interventions. Also, it is necessary to research how healthcare professionals, specifically in rural regions, can incorporate the data collected by IoT biosensors into clinical decision-making. The significance of IoT technologies in the Indian healthcare setting would be to understand how healthcare systems would use this data to facilitate better patients care.

5.7 Reflection

Completing this dissertation has deepened my understanding of the complexity of technology adoption in healthcare, especially in a diverse country like India. It has highlighted the importance of user-centred design and the need for cultural sensitivity in digital health interventions. This project has reshaped my perspective on the potential of IoT to transform chronic disease management, particularly for underserved populations.

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APPENDICES

APPENDIX 1: PRIVACY AND CONSENT AGREEMENT

Patient Perspectives on IoT- Enabled Biosensors for Diabetes Management in India

You are invited to take part in an academic research study conducted by Feby Mathew, am a postgraduate student enrolled in the MSc in Digital Transformation (Life Sciences) at Griffith College. I am conducting a research study as part of my Master's dissertation. This study explores how Indian diabetic patients use and experience IoT-enabled biosensor devices like Freestyle Libre, Beat O and similar technologies. The purpose of the study is to understand their usability, effectiveness, challenges, and the factors influencing adoption in the Indian healthcare context. The findings aim to contribute to better digital health solutions and improved patient care in India.

You will be asked to participate in an anonymous online questionnaire, which should take approximately 5-10 minutes. The questionnaire will be comprised of multiple choice questions and a few open questions about your experience of the use of IoT biosensors to manage diabetes. . No personal identifying information (e.g., names, emails, IP addresses) will be collected. Data will be retained for a maximum of two years for academic purposes and then deleted permanently.

You can choose not to answer any question or exit the survey at any time. There are no risk to participating, and your responses will help support patient-centred innovation in diabetes care in India.Thank you for your time and valuable input.

APPENDIX 2: QUESTIONNAIRE

Section 1

Consent

1.Do you consent to participate in this research study?

- o I understood the information above and the research is about
- o Yes, I consent to participate in this research study

Section 2

Demographics Profile

2.Age Group Required to answer.

- o 18-30
- o 31-45
- o 46-60
- o 61 and above

3.Gender

- Male
- Female
- Other
- Prefer not to say

4.Current Residence

- Urban
- Semi-urban
- Rural

5.Highest Education Level

- No formal education
- Primary education
- Secondary education
- Undergraduate degree
- Postgraduate or higher

6.Type of Diabetes

- Type 1
- Type 2
- Not sure

7.Years Living with Diabetes

- Less than 1 year
- 1-3 years
- 4-6 years
- More than 6 years

Section 3

Awareness & Exposure to IoT- Based Biosensors

8.Are you aware of smart glucose glucose monitoring devices like Freestyle Libre, Beat O, or Bionime?

- Yes
- No

9.How did you first learn about these devices?

- Doctor or healthcare provider
- Social media/Internet
- Family or Friends
- Pharmacy
- Other

10.Have you ever used an IoT-based biosensor device?

- Yes - currently using
- Yes - used in the past
- No - but aware of them
- No - Never

11.If you've never used one, what is the main reason?

- Too expensive
- Don't know how to use it
- Not available in my area
- Don't trust the technology
- Not recommended by my doctor
- Other

Section 4

Device Usage & Usability (For users or past users only)

12.Which device have you used?.

- Freestyle Libre
- Beat O
- Bionime
- Dexcom
- Other

13.How often do you use the device?

- Several times per day
- Once per day
- A few times per week
- Rarely

14.How easy was the device to use?

- Very easy
- Somewhat easy
- Neutral
- Somewhat difficult
- Very difficult

15.Have you encountered any technical or device-related issues?

- Yes
- No
- If yes, please explain briefly
- Other

16.Please describe any challenges you faced while using the device?

Enter your answer

Section 5

Perceived Benefits & Lifestyle Impact

17.How satisfied are you with the device's overall performance?

- Very satisfied
- Satisfied
- Neutral
- Dissatisfied
- Very dissatisfied

18.To what extent has the device helped you manage your blood glucose?

- Significantly improved control
- Somewhat improved
- No change
- Not sure

19.In your own words, how has the device changed your self-care or lifestyle?

Enter your answer

20.Has the device helped you feel more independent in managing your condition?

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree

Section 6

Digital Literacy & Confidence

21.How comfortable are you using smartphones or health-related apps?

- Very comfortable
- Somewhat comfortable
- Neutral
- Uncomfortable

22.Did you receive help to learn how to use the biosensor or its app?

- Yes - from family or friends
- Yes - from a healthcare provider
- No - I learned on my own

23.Do you feel you need more training or support to use the device effectively?

- Yes
- No
- Maybe

Section 7

Barriers & Systemic Challenges

24.What are the biggest barriers to using such devices in India?

- Cost/affordability
- Poor internet access
- Lack of awareness
- Lack of training or support
- Privacy concerns
- Cultural beliefs
- Unavailability in my region
- Other

25.Are you concerned about data privacy while using connected health devices?

- Yes
- No
- Not sure
- Please explain your concerns
- Other

Section 8

Recommendation & Future Improvements

26.What improvements would you suggest for IoT biosensors to make them more useful or user-friendly?

Enter your answer

27.Do you think such devices should be supported or subsidised under India's public health system(e.g., Insurance/government schemes)?

- Yes
- No
- Not sure
- Why or why not?

Ethics Application & Declaration Form

DISSERTATION TITLE: EXPLORING THE USE OF IoT-ENABLED BIOSENSORS FOR DIABETES CARE PERSPECTIVES FROM INDIAN PATIENTS

RESEARCHER'S NAME: FEBY MATHEW

PROGRAMME OF STUDY: MSC DIGITAL TRANSFORMATION (LIFE SCIENCES)

SUPERVISOR'S NAME: DINESH REDDY

DECLARATION:
The information in this application form is accurate to the best of my knowledge. I undertake to abide by the principles outlined by Innopharma/Griffith College ethics policy in my research dissertation. I confirm that I have completed a full ethics assessment for my research dissertation as per the college guidelines. I will not begin my primary research until such approval from my supervisor and/or ethics Committee has been obtained.
I pledge to carry out my research according to the Innopharma/Griffith College academic integrity standards. Any results presented in my dissertation will be from my own, original research, I will reference and/or acknowledge any material or sources used in its preparation and I will not plagiarise the work of anyone else.

For Student:

STUDENT SIGNATURE:

DATE: 08/07/2025

The research contained within this research dissertation proposal has been approved.

For Supervisor:
Ethics Committee Approval Required: Yes [ ] No [X]

SUPERVISOR SIGNATURE:

DATE:

For Ethics Committee (if required):
Ethics Committee Approval Given: Yes [ ] No [ ]

ETHICS COMMITTEE MEMBER SIGNATURE:

GRIFFITH COLLEGE

DATE:

NOTE: Supervisors are responsible for ensuring their students fill in this form correctly and that all ethical areas have been considered.

SECTION 1: DESCRIPTION OF RESEARCH STUDY

1.1 **Purpose and objectives of research** *[300 words maximum/ use literature review findings to guide]*
More people than 77 million in India are suffering from diabetes, and it is increasing steadily. For the treatment of this chronic disease, real-time blood glucose monitoring is necessary. Traditional methods such as finger-prick glucometers are painful, non-user-friendly, and non-compliant. Real-time and continuous monitoring with the help of IoT-sensing biosensors such as Freestyle Libre and BeatO is less painful, less non-user-friendly, and very compliant. In spite of widespread global research, few studies have been published about Indian diabetic patients' attitude and use of these technologies—especially with regard to usability, digital literacy, costs, and adoption in healthcare.

Current studies will examine the perception, adoption, and usage of IoT-enabled biosensors among Indian diabetic patients. It will assess perceived usefulness (e.g., improved self-management, real-time feedback), ease of use concerns, price, and adoption barriers (e.g., computer literacy, internet penetration, and geographical variation). This patient-centered study seeks to resolve literature inconsistency and inform digital health device development as well as deployment optimization.

Research Objectives:

To explore the usage of IoT-based biosensors among diabetic patients in India at present.
To determine the benefits and limitations of IoT-based biosensor use from the perspective of the patients.
To identify the areas for possible improvement of IoT-based diabetes control technology in the years to come.
To assess the degree to which the self-care and quality of life of the patients depend on such devices.
To examine the level of awareness and digital literacy among Indian diabetic patients regarding IoT-enabled healthcare devices.
To identify the barriers to adoption (technological, economic, or social) of IoT-enabled biosensors in Indian healthcare.

1.2 **Research methodology:** *[300 words maximum/ detail how you will acquire your primary data (focus groups/interviews/online surveys etc). Proposed questions for questionnaires and/or interviews* ***must be included*** *in the appendix].*

This research utilizes a pragmatic survey research design to examine patient experience with IoT-based biosensors for diabetes care in India. Primary data will be collected by administering an online survey via Microsoft Forms or Google Forms. This is a powerful, scalable, and appropriate mode of reaching geographically dispersed participants in India.

The questionnaire will be a combination of closed-ended questions (quantitative data) and open-ended questions (gather qualitative data on personal experiences). Thematic areas are: demographics, use of biosensor, usability and satisfaction, perceived health effects, perceived barriers to its use, digital competence, and ideas for change.

The sample will be drawn from respondents who will be purposively recruited by non-probability sampling of adults (over 18 years) with Type 1 or Type 2 diabetes who ever used or are currently using IoT-based biosensors like FreeStyle Libre, BeatO, or Bionime. The recruitment will be through diabetes online forums (e.g., WhatsApp, Facebook), online health-tech forums, and snowball sampling through patient networks. The identity information will not be collected, and it will be completely anonymous and voluntary.

Closed-ended quantitative data will be analyzed using descriptive statistics (percentages, frequencies, and cross-tabulations) in Excel or SPSS to identify trends in usage of the device, satisfaction, and barriers. Open-ended qualitative data will be hand-coded or by computer program such as NVivo to identify themes that emerge repeatedly on user experience and suggestions for future development.

This patient-centered, ethical, and low-cost methodology design is employed to study real-world use of digital health technologies in India. The survey instrument can be found in the appendix of this application for perusal.

SECTION 2: POSSIBLE ETHICAL ISSUES

Answer 'yes' or 'no' to the following questions.

SUBJECT MATTER

Does the research proposal involve:

Research into specific company activities that would be deemed sensitive or confidential	Yes No✓
Research into politically and/or racially/ethnically and/or commercially sensitive areas	Yes No✓
Sensitive, personal, professional or corporate issues	Yes No✓

RESEARCH PROCEDURES

Does the research proposal involve:

Research that might damage the reputation of companies or participants	Yes No✓
Research that may negatively affect the reputation of Griffith College/Innopharma	Yes No✓
Use of personal records without consent	Yes No✓
Use of company data without consent	Yes No✓
The offer of any inducements to participate	Yes No✓
Audio or visual recording without consent	Yes No✓
Using a language other than English	Yes No✓

PARTICIPANTS

Does the research proposal involve:

People who are not competent and/or fluent in English	Yes No✓
Does your research group include any of the following vulnerable groups	Yes No✓

(Adults with psychological impairments; Adults with learning difficulties; Adults under the protection/control /influence of others (e.g. in care/prison); Relatives of ill people (e.g. parents of sick children); Hospital or GP participants recruited in a medical facility; persons under the age of 18)

<u>If you have answered NO to ALL questions, please go straight to Section 4.</u>

<u>If you have answered YES to ANY question in SECTION 2, you must fill in SECTION 3.</u>

SECTION 3: STEPS TAKEN TO AVOID ETHICAL ISSUES

[Only fill in this section if you answered YES to ANY of the questions in Section 3. For example, if you answered yes to including participants who are not fluent in English, you might put forward a plan that offers your survey in two languages to take this into account. Another example could be a study where the researcher wants to include information about the care received by children with a long-term condition but it would not be ethical to approach the children directly but it might be acceptable to instead ask parents questions about their child's care. If these plans are acceptable to your supervisor, you may not need to apply for ethical approval from the Ethics Committee].

3.1. If your ethics relates to ***Subject Matter***, outline your action plan to work around any sensitive issues.
3.2. If your ethics relates to ***Research Procedures***, outline your action plan to deal with possible ethical issues in your research procedures.
3.3. If your ethics relates to ***Participants***, outline how you will protect vulnerable persons or those that do not have English as their first language.

SECTION 4: ABOUT YOUR PARTICIPANTS

4.1. Outline your participant profile and why you have chosen them for this study *[Do not provide names except where it is deemed impossible to conceal identity].*

Recipients are Indian nationals 18 years or above of age, with Type 1 or Type 2 diabetes, and who are already utilizing or have utilized IoT-based biosensors such as FreeStyle Libre or Beat O etc. They are chosen as they are direct or primary users of the aforementioned health technologies and can provide first-hand information on user experience and technology adoption in Indian healthcare.

4.2 How do you plan to gain access to/contact/approach your participant(s).

Recruitment will be conducted through diabetes-related Facebook and WhatsApp groups, online forums, snowball sampling and patient support networks. Initial contact will consist of study description, participant rights, and a link to the consent-based online survey.

SECTION 5: INFORMATION, CONSENT AND CONFIDENTIALITY

5.1 **Participant Information Letter (PIL) for participants**

[You must submit an information letter for participants with this application, as part of your appendices document. For online surveys, it is sufficient to include a paragraph summarising and explaining the purpose of the research at the beginning of the survey. In all other research e.g. interviews, phonecalls, a PIL should be provided to each participant before they are asked for their consent to take part. A template PIL is available in Moodle].

Please confirm below that your information letter covers:

Description of the research topic and method	Yes ✓No
Details of what participation will involve	Yes ✓No
Rights to anonymity	Yes ✓No
Confidentiality	Yes ✓No
Rights to withdraw from the research	Yes ✓No
The contact details of the researcher and supervisor (if necessary)	Yes ✓No

5.2 **Informed Consent Form (ICF) for participants**

[Informed consent is required for most research. For online surveys, it is sufficient to get the participant to tick two boxes at the beginning of the survey – one to state they understand the research and one to give consent. In all other research e.g. interviews, phonecalls, a signed consent form is required. If the data is gathered online e.g. zoom, a signed consent form can be scanned and sent to the researcher. A template ICF is available in Moodle. The signed ICFs, along with the surveys, audio files or interview notes etc. must be stored in the primary data folder on moodle and can be accessed by Innopharma staff for the purposes of verifying the authenticity of the research carried out and the data collected].

Please indicate below if your research requires a signed consent form by selecting the relevant option only:

No: my research study involves an online survey only and/or does not require signed consent

SECTION 6: STORAGE OF DATA

[Please ensure that you are abiding by GDPR and the national Data protection laws https://www.hrb.ie/funding/gdpr-guidance-for-researchers/gdpr-and-health-research/).

The student is responsible for storage of data and this will be handed over to the college in an electronic format as part of the thesis submission i.e. primary data and completed ICFs where applicable will be added to the primary data folder on

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*moodle. The rationale is to keep data **as long as it is still useful** and there is an intention to use it further **for research** so if this is not the case then this can be stipulated here and a shorter retention period given.]*

6.1. How will you store the research data and for how long? How will you manage data protection issues?

All research data, including survey responses and analysis files, shall be stored securely on an encrypted electronic device with a password. The primary storage device shall be the researcher's own laptop, encrypted and password-protected with a solid, personal password. A backup version of the data shall also be stored in a secure cloud storage service (Microsoft OneDrive) to avoid loss due to hardware failure or other unforeseen circumstances.

All data will be retained for a period of not more than two years from the date of the award of the qualification. This aligns with academic and data protection policy to facilitate potential re-analysis, audit, or validation of outcomes. At the expiry of the retention period, all the files will be securely and irretrievably erased from both local and cloud storage by appropriate data destruction practices.

To ensure data protection, the following strategies will be followed:

Anonymization

All personal identifiers (names, emails, contact numbers, or IP addresses), if collected, will be destroyed or substituted with non-identifiable codes. No information that personally identifies a person will be collected through this online survey of the study.

Password Protection

All research papers shall be stored in encrypted folders and protected with strong, personal passwords. These details shall be available only to the researcher.

Access Restrictions

Access to data shall be limited strictly to the researcher and academic supervisor. As part of the dissertation submission process, the anonymised raw data may be imported into Moodle for purposes of marking and academic record only.

Data Encryption

Both the device-based and cloud-based data storage systems are encrypted, so data is inaccessible without authorisation even when lost or stolen.

The multi-layered data management plan is designed to ensure participant confidentiality, data integrity, and compliance with GDPR and college ethics requirements for research.

SECTION 7: NON-DISCLOSURE AGREEMENT & STUDENT CONSENT

7.1 **Non-Disclosure Agreement (NDA)**
Will the final dissertation contain any information pertaining to any source what would warrant the use of a Non-Disclosure Agreement (NDA) e.g. industry-based research?

Yes No✓

7.2 **Student consent**
If a Non-Disclosure Agreement (NDA) is not required, does the Student consent to allow their completed dissertation to be held/published by Innopharma/Griffith College?

Yes✓ No

SECTION 8: RECORDING AND RETENTION OF DISSERTATION VIVA

8.1 **Viva Recording**
The Dissertation viva will be recorded. This recording may be used to facilitate assessment by Innopharma staff, a third reader if necessary and/or if requested by the external examiner for the Programme. The recording will be held in line with current GDPR guidelines and will not be made publicly available.

SECTION 9: DOCUMENT CHECKLIST

NOTE: Applicants must attach the following documents in electronic format to the appendix.

Which documents are added to the appendix? Please tick N/A if not applicable:

9.1 Participant Information Letter (PIL) for participant	Yes✓ N/A
9.2 Informed Consent Form (ICF) for participant	Yes N/A✓
9.3 Questions/survey for interviewees/focus groups etc *(can be in draft form)*	Yes✓ N/A
9.4 Any other documents e.g. Non-Disclosure Agreement	Yes N/A✓

I confirm that this application is complete and all required documents are included in the appendix.

For Student:

STUDENT SIGNATURE: [signature]

DATE: 08/07/2025

SECTION 10: APPENDIX

GRIFFITH COLLEGE

Participant Information Letter

TITLE OF THE STUDY: Exploring the Use of IoT-Enabled Biosensors for Diabetes Care: Perspectives from Indian Patients

I would like to invite you to take part in a research study. Before you decide you need to understand why the research is being done and what it would involve for you. Please take time to read the following information carefully. Ask questions if anything you read is not clear or if you would like more information. Take time to decide whether or not to take part.

WHO I AM AND WHAT THIS STUDY IS ABOUT

My name is Feby Mathew, and I am a postgraduate student enrolled in the MSc in Digital Transformation (Life Sciences) at Griffith College. I am conducting a research study as part of my Master's dissertation. This study explores how Indian diabetic patients use and experience IoT-enabled biosensor devices like Freestyle Libre, Beat O and similar technologies. The aim is to better understand their usability, effectiveness, challenges, and the factors influencing adoption in the Indian healthcare context.

WHAT WOULD TAKING PART INVOLVE?

You will be asked to participate in an anonymous online questionnaire, which should take approximately 5-10 minutes. The questionnaire will be comprised of multiple choice questions and a few open questions about your experience of the use of IoT biosensors to manage diabetes. Your participation is completely voluntary, and you can refuse to respond to any question or withdraw at any time without reason and with no negative consequences.

WHY HAVE YOU BEEN INVITED TO TAKE PART?

You are being asked to take part because you are an Indian citizen, 18 years or older and have Type 1 or Type 2 diabetes and have experience of having (currently or in the past) used an IoT-based biosensor such as Freestyle Libre, Beat O, Bionime, or the like.

DO YOU HAVE TO TAKE PART?

Participation is voluntary and confidential. You may refuse or withdraw at any moment during the research. Your decision will not produce any unfavourable or negative outcome.

WHAT ARE THE POSSIBLE RISKS AND BENEFITS OF TAKING PART?

There are no risks expected in this research. Although there may not be any obvious benefit for you, your responses will provide valuable input into the design and development of digital health technologies for diabetes care in India.

WILL TAKING PART BE CONFIDENTIAL?

Yes. Everything you answer will be anonymous and confidential. No personal identifying information (e.g., names, emails, IP addresses) will be collected. The academic supervisor and researcher alone will see anonymised data. Confidentiality of the data will only be compromised if there is a safety concern (e.g., risk of harm to yourself or others).

HOW WILL INFORMATION YOU PROVIDE BE STORED AND PROTECTED?

All data will be stored safely on an encrypted and password-protected device and in cloud storage. Data will be retained for a maximum of two years following qualification awarding and then deleted permanently. No data that can identify a person will be asked for or kept.

WHAT WILL HAPPEN TO THE RESULTS OF THE STUDY?

The results will be integrated into my Master's thesis, which may be accessed through Griffith College's library. Main findings can also be used for teaching or conference presentations.

WHO SHOULD YOU CONTACT FOR FURTHER INFORMATION?

Researcher: Feby Mathew
Email: febymathew1998@gmail.com
Affiliation: Griffith College

THANK YOU

GRIFFITH COLLEGE

Survey questionnaire

Patient Perspectives on IoT- Enabled Biosensors for Diabetes Management in India
You are invited to take part in an academic research study conducted by Feby Mathew, am a postgraduate student enrolled in the MSc in Digital Transformation (Life Sciences) at Griffith College. I am conducting a research study as part of my Master's dissertation. This study explores how Indian diabetic patients use and experience IoT-enabled biosensor devices like Freestyle Libre, Beat O and similar technologies. The purpose of the study is to understand their usability, effectiveness, challenges, and the factors influencing adoption in the Indian healthcare context. The findings aim to contribute to better digital health solutions and improved patient care in India.

You will be asked to participate in an anonymous online questionnaire, which should take approximately 5-10 minutes. The questionnaire will be comprised of multiple choice questions and a few open questions about your experience of the use of IoT biosensors to manage diabetes. . No personal identifying information (e.g., names, emails, IP addresses) will be collected. Data will be retained for a maximum of two years for academic purposes and then deleted permanently.

You can choose not to answer any question or exit the survey at any time. There are no risk to participating, and your responses will help support patient-centred innovation in diabetes care in India.

Thank you for your time and valuable input.

Section 1 Consent
1.Do you consent to participate in this research study?
I understood the information above and what the research is about
Yes, I consent to participate in this research study

Section 2 Demographic Profile
2.Age Group
18-30
31-45
46-60
61 and above

3.Gender
Male
Female
Other
Prefer not to say

4.Current Residence
Urban
Semi-urban
Rural

5.Highest Education Level
No formal education
Primary education
Secondary education
Undergraduate degree
Postgraduate or higher

6.Type of Diabetes
Type 1
Type 2
Not sure

7.Years Living with Diabetes
Less than 1 year
1-3 years
4-6 years
More than 6 years

Section 3
Awareness & Exposure to IoT- Based Biosensors

8.Are you aware of smart glucose glucose monitoring devices like Freestyle Libre, Beat O, or Bionime?Required to answer.
Yes
No

9.How did you first learn about these devices?
Doctor or healthcare provider
Social media/Internet
Family or Friends
Pharmacy
Other

10.Have you ever used an IoT-based biosensor device?
Yes - currently using
Yes - used in the past
No - but aware of them
No - Never

11.If you've never used one, what is the main reason?
Too expensive
Don't know how to use it
Not available in my area
Don't trust the technology
Not recommended by my doctor
Other

Section 4
Device Usage & Usability (For users or past users only)

12.Which device have you used?
Freestyle Libre
Beat O
Bionime
Dexcom
Other

13.How often do you use the device?
Several times per day
Once per day
A few times per week
Rarely

14.How easy was the device to use?
Very easy
Somewhat easy
Neutral
Somewhat difficult
Very difficult

15.Have you encountered any technical or device-related issues?
Yes
No
If yes, please explain briefly
Other

16.Please describe any challenges you faced while using the device?
Enter your answer

Section 5
Perceived Benefits & Lifestyle Impact

17.How satisfied are you with the device's overall performance?
Very satisfied
Satisfied
Neutral
Dissatisfied
Very dissatisfied

18.To what extent has the device helped you manage your blood glucose?
Significantly improved control
Somewhat improved
No change
Not sure

19.Has the device helped you feel more independent in managing your condition?
Strongly agree
Agree
Neutral
Disagree
Strongly disagree

20.In your own words, how has the device changed your self-care or lifestyle?
Enter your answer

Section 6
Digital Literacy & Confidence

21.How comfortable are you using smartphones or health-related apps?
Very comfortable
Somewhat comfortable
Neutral
Uncomfortable

22.Did you receive help to learn how to use the biosensor or its app?
Yes - from family or friends
Yes - from a healthcare provider
No - I learned on my own

23.Do you feel you need more training or support to use the device effectively?
Yes
No
Maybe

Section 7
Barriers & Systemic Challenges

24.What are the biggest barriers to using such devices in India?
Cost/affordability
Poor internet access
Lack of awareness
Lack of training or support
Privacy concerns
Cultural beliefs
Unavailability n my region
Other

25.Are you concerned about data privacy while using connected health devices?
Yes
No
Not sure
Please explain your concerns
Other

Section 8
Recommendation & Future Improvements

26.What improvements would you suggest for IoT biosensors to make them more useful or user-friendly?
Enter your answer

27.Do you think such devices should be supported or subsidised under India's public health system(e.g., Insurance/government schemes)?
Yes
No
Not sure
Why or why not?