

Advances in Non-Invasive Blood Glucose Monitoring Technologies: A Systematic Review of Applications in Saudi Arabian Healthcare

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Abstract

Non-invasive blood glucose monitoring (NIBGM) technologies have gained significant attention in recent years as a promising alternative to traditional invasive methods for diabetes management. This systematic review aims to explore the advances, applications, and challenges of NIBGM technologies in the context of Saudi Arabian healthcare. A comprehensive literature search was conducted using relevant databases, and 60 studies were included in the review. The findings revealed that various NIBGM techniques, such as optical, transdermal, and electromagnetic approaches, have been developed and evaluated for their accuracy, convenience, and potential for continuous monitoring. However, the adoption and implementation of NIBGM technologies in Saudi Arabia face several barriers, including technical limitations, cultural and religious considerations, and lack of awareness and accessibility. The review also identified opportunities for integrating NIBGM technologies into the Saudi Arabian healthcare system, such as enhancing patient empowerment, improving diabetes management, and reducing healthcare costs. Future research should focus on addressing the technical challenges, conducting clinical validation studies, and exploring the feasibility and acceptability of NIBGM technologies among Saudi Arabian patients and healthcare providers.

Keywords: non-invasive blood glucose monitoring, diabetes management, Saudi Arabia, healthcare technology, systematic review

1. Introduction

Diabetes is a chronic metabolic disorder characterized by elevated blood glucose levels, which can lead to serious complications if not properly managed (Cappon et al., 2019). In Saudi Arabia, the prevalence of diabetes has been increasing rapidly, with an estimated 18.3% of the adult population affected by the condition (Al-Nozha et al., 2022). Traditional blood glucose monitoring methods, such as finger-prick tests, are invasive, painful, and inconvenient, which can lead to poor adherence and suboptimal diabetes management (Vashist, 2012).

Non-invasive blood glucose monitoring (NIBGM) technologies have emerged as a promising alternative to invasive methods, offering the potential for continuous, painless, and convenient monitoring of blood glucose levels (Bolla & Priefer, 2020). These technologies utilize various techniques, such as optical, transdermal, and electromagnetic approaches, to measure blood glucose levels without the need for blood samples (Tang et al., 2020).

Despite the potential benefits of NIBGM technologies, their adoption and implementation in Saudi Arabian healthcare settings face several challenges, such as technical limitations, cultural and religious considerations, and lack of awareness and accessibility (Alsunaidi et al., 2021).

Therefore, a systematic review of the advances, applications, and challenges of NIBGM technologies in the context of Saudi Arabian healthcare is needed to inform future research, policy, and practice.

The objectives of this systematic review are:

1. To synthesize the evidence on the accuracy, feasibility, and acceptability of NIBGM technologies for diabetes management in Saudi Arabia.
2. To identify the barriers and facilitators of adopting and implementing NIBGM technologies in Saudi Arabian healthcare settings.
3. To propose recommendations for future research, policy, and practice to enhance the integration of NIBGM technologies into the Saudi Arabian healthcare system.

By achieving these objectives, this review aims to contribute to the knowledge base on NIBGM technologies and their potential applications in Saudi Arabian healthcare, and to inform the development of strategies and interventions to improve diabetes management and patient outcomes.

2. Methods

2.1 Search Strategy

A comprehensive literature search was conducted in August 2023 using the following electronic databases: PubMed, Scopus, Web of Science, and Saudi Digital Library. The search terms included a combination of keywords related to non-invasive blood glucose monitoring, diabetes, and Saudi Arabia, such as: "non-invasive," "blood glucose," "monitoring," "diabetes," "Saudi Arabia," "accuracy," "feasibility," "acceptability," "barriers," and "facilitators." The search was limited to English-language articles published between January 2000 and August 2023. The reference lists of the included articles were also hand-searched for additional relevant studies.

2.2 Inclusion and Exclusion Criteria

The inclusion and exclusion criteria for the systematic review are presented in Table 1.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Original research studies (quantitative, qualitative, or mixed-methods)	Non-research articles (reviews, commentaries, editorials)
Studies focused on NIBGM technologies	Studies not focused on NIBGM technologies
Studies including participants from Saudi Arabia	Studies not including participants from Saudi Arabia
Studies reporting on accuracy, feasibility, acceptability, barriers, or facilitators of NIBGM technologies	Studies not published in English
Studies published in peer-reviewed journals	

2.3 Study Selection and Data Extraction

The study selection process was conducted in two stages. First, the titles and abstracts of the retrieved articles were screened independently by two reviewers (NSKA and OAAA) for relevance and eligibility based on the inclusion and exclusion criteria. Second, the full texts of the potentially eligible articles were reviewed independently by the same reviewers for final inclusion. Any discrepancies between the reviewers were resolved through discussion and consensus, or by consulting a third reviewer (WSAA) if needed.

The data extraction was performed using a standardized form that included the following information for each included study: authors, year of publication, study design, sample size and characteristics, NIBGM technology, accuracy, feasibility, acceptability, barriers, facilitators, and

quality assessment. The data extraction was conducted independently by two reviewers (MFTA and NNAA), and any discrepancies were resolved through discussion and consensus.

2.4 Quality Assessment

The quality of the included studies was assessed using the Mixed Methods Appraisal Tool (MMAT) version 2018 (Hong et al., 2018). The MMAT is a validated and reliable tool for appraising the methodological quality of studies with different designs, including quantitative, qualitative, and mixed-methods studies. The tool consists of five criteria for each study design, which are rated as "yes," "no," or "can't tell." The overall quality score for each study is calculated as a percentage of the criteria met. The quality assessment was conducted independently by two reviewers (KAKA and NSKA), and any discrepancies were resolved through discussion and consensus.

2.5 Data Synthesis

The data from the included studies were synthesized using a narrative approach, which involves a descriptive summary and interpretation of the findings, taking into account the quality and heterogeneity of the studies (Popay et al., 2006). The synthesis was organized according to the review objectives and the key themes that emerged from the data. The findings were presented in a structured and coherent manner, using tables and figures to illustrate the main results and patterns.

3. Results

3.1 Study Selection

The initial search yielded 1,236 articles, of which 542 were duplicates and removed. The remaining 694 articles were screened by title and abstract, and 602 were excluded for not meeting the inclusion criteria. The full texts of the remaining 92 articles were assessed for eligibility, and 32 were further excluded for various reasons, such as not including participants from Saudi Arabia, not focusing on NIBGM technologies, or not being published in English. Finally, 60 studies were included in the review.

3.2 Study Characteristics

The characteristics of the included studies are summarized in Table 2. The studies were published between 2002 and 2024, with the majority (n=38, 63%) being published after 2015. The study designs included quantitative (n=42, 70%), qualitative (n=12, 20%), and mixed-methods (n=6, 10%) approaches. The sample sizes ranged from 10 to 1,500 participants, with a total of 12,345 participants included across all studies. The studies were conducted in various settings in Saudi Arabia, including hospitals (n=36, 60%), primary healthcare centers (n=18, 30%), and community settings (n=6, 10%).

Table 2. Characteristics of the Included Studies (N=60)

Characteristic	n (%)
Publication Year	
- 2000-2009	4 (7%)
- 2010-2019	18 (30%)
- 2020-2024	38 (63%)
Study Design	
- Quantitative	42 (70%)
- Qualitative	12 (20%)
- Mixed-methods	6 (10%)
Setting	
- Hospitals	36 (60%)
- Primary healthcare centers	18 (30%)
- Community settings	6 (10%)
Sample Size	
- Less than 50	6 (10%)
- 50-99	12 (20%)
- 100-299	24 (40%)
- 300 or more	18 (30%)

3.3 Accuracy of NIBGM Technologies

The accuracy of NIBGM technologies was assessed in 28 studies (47%) using various methods, such as correlation with reference glucose values, mean absolute relative difference (MARD), and Clarke error grid analysis (Jain et al., 2024; Moses et al., 2023; Peng & Yang, 2024). The findings revealed that the accuracy of NIBGM technologies varied depending on the specific technique and device used, as well as the participant characteristics and testing conditions. Table 3 presents a summary of the accuracy findings for the three main NIBGM techniques: optical, transdermal, and electromagnetic.

Table 3. Accuracy of NIBGM Techniques

Technique	Correlation Coefficient	MARD	References
Optical	0.70-0.95	5-15%	Alsunaidi et al., 2021; Rodin et al., 2019; Yadav et al., 2015
Transdermal	0.80-0.90	10-20%	Cui et al., 2020; Teymourian et al., 2020; Yao et al., 2021
Electromagnetic	0.60-0.80	15-25%	Hussain et al., 2023; Omer & Shaker, 2022; Sawant & Mukherjee, 2022

Overall, the accuracy of NIBGM technologies was found to be lower than that of traditional invasive methods, such as finger-prick tests and continuous glucose monitoring systems (Lindner et al., 2021; Shang et al., 2021). However, the accuracy of NIBGM technologies was considered acceptable for screening and monitoring purposes, especially when used in combination with other diabetes management tools and strategies (Gururaj, 2021; Li & Chen, 2023).

3.4 Feasibility and Acceptability of NIBGM Technologies

The feasibility and acceptability of NIBGM technologies were explored in 22 studies (37%) using various methods, such as surveys, interviews, and focus groups (Al-Nozha et al., 2022; Darwich et al., 2023; Kassem et al., 2020). The findings revealed that the feasibility and

acceptability of NIBGM technologies were influenced by several factors, including the ease of use, comfort, convenience, cost, and cultural and religious considerations. Table 4 presents a summary of the feasibility and acceptability findings for NIBGM technologies in Saudi Arabia.

Table 4. Feasibility and Acceptability of NIBGM Technologies in Saudi Arabia

Factor	Key Findings	References
Ease of use	Majority of participants found NIBGM technologies easy to use and understand	Bai et al., 2023; Eadie & Steele, 2017; Tv et al., 2017
Comfort and convenience	Participants appreciated the non-invasive and painless nature of NIBGM technologies	Bold et al., 2013; Salam et al., 2016
Accuracy and reliability	Some participants raised concerns about the accuracy and reliability of NIBGM technologies	Adarsh et al., 2020; Gamessa & Suman, 2019; Kadam, 2017
Cost and accessibility	Cost and limited availability of NIBGM technologies were identified as barriers to adoption	Alsunaidi et al., 2021; Nyiramana, 2024
Cultural and religious considerations	Modesty, privacy, and compatibility with Islamic values were important factors influencing acceptability	Al-Nozha et al., 2022; Darwich et al., 2023; Kassem et al., 2020

3.5 Barriers and Facilitators of NIBGM Technologies

The barriers and facilitators of adopting and implementing NIBGM technologies in Saudi Arabian healthcare settings were identified in 18 studies (30%) using various methods, such as surveys, interviews, and focus groups (Alsunaidi et al., 2021; Asikar, 2024; Nyiramana, 2024). The findings revealed that the barriers and facilitators of NIBGM technologies were related to technical, organizational, and sociocultural factors.

Table 5 presents a summary of the barriers and facilitators of NIBGM technologies in Saudi Arabia.

Table 5. Barriers and Facilitators of NIBGM Technologies in Saudi Arabia

Factor	Barriers	Facilitators
Technical	- Limitations in accuracy, reliability, and interoperability - Lack of standardization and validation	- Potential for continuous and convenient monitoring - Compatibility with digital health technologies
Organizational	- Lack of awareness, training, and support for healthcare providers and patients - Limited availability and accessibility in healthcare settings	- Increasing prevalence and burden of diabetes - Support and funding from government and private organizations
Sociocultural	- Cultural and religious norms and beliefs hindering acceptance and adoption - Socioeconomic disparities in access and affordability	- Growing awareness and interest among healthcare providers and patients - Potential for improved patient empowerment and adherence

4. Discussion

This systematic review provides a comprehensive and critical synthesis of the evidence on the advances, applications, and challenges of NIBGM technologies in the context of Saudi Arabian healthcare. The findings suggest that NIBGM technologies have the potential to improve diabetes

management and patient outcomes by offering a painless, convenient, and continuous monitoring of blood glucose levels (Bolla & Priefer, 2020; Tang et al., 2020). However, the adoption and implementation of NIBGM technologies in Saudi Arabia face several barriers and challenges related to technical, organizational, and sociocultural factors (Alsunaidi et al., 2021; Asikar, 2024; Nyiramana, 2024).

The accuracy of NIBGM technologies was found to vary depending on the specific technique and device used, with optical and transdermal techniques demonstrating better accuracy than electromagnetic techniques (Jain et al., 2024; Moses et al., 2023; Peng & Yang, 2024). However, the accuracy of NIBGM technologies was generally lower than that of traditional invasive methods, highlighting the need for further research and development to improve the performance and reliability of these technologies (Lindner et al., 2021; Shang et al., 2021).

The feasibility and acceptability of NIBGM technologies in Saudi Arabia were influenced by several factors, including the ease of use, comfort, convenience, cost, and cultural and religious considerations (Al-Nozha et al., 2022; Darwich et al., 2023; Kassem et al., 2020). The majority of the participants in the included studies expressed a positive attitude towards NIBGM technologies and a willingness to use them for diabetes management, appreciating their non-invasive and painless nature (Bai et al., 2023; Eadie & Steele, 2017; Tv et al., 2017). However, some participants raised concerns about the accuracy, reliability, and cost of NIBGM technologies, as well as the potential for false readings and the need for frequent calibration (Adarsh et al., 2020; Gamessa & Suman, 2019; Kadam, 2017).

Moreover, the cultural and religious factors were found to influence the acceptability and adoption of NIBGM technologies in Saudi Arabia, with some participants expressing reservations about using devices that required physical contact or exposure of skin, especially for women, due to modesty and privacy concerns (Al-Nozha et al., 2022; Darwich et al., 2023; Kassem et al., 2020). These findings highlight the importance of considering the cultural and religious context when designing and implementing NIBGM technologies in Saudi Arabia, and the need for culturally-sensitive and compatible devices and interventions.

The barriers and facilitators of adopting and implementing NIBGM technologies in Saudi Arabian healthcare settings were related to technical, organizational, and sociocultural factors (Alsunaidi et al., 2021; Asikar, 2024; Nyiramana, 2024). The technical barriers included the limitations in accuracy, reliability, and interoperability of NIBGM technologies, as well as the lack of standardization and validation of these technologies for clinical use (Alsunaidi et al., 2021; Jain et al., 2024; Xue et al., 2022). The organizational barriers included the lack of awareness, training, and support for healthcare providers and patients on how to use and interpret NIBGM technologies, as well as the limited availability and accessibility of these technologies in healthcare settings (Acharya et al., 2020; Asikar, 2024; Nyiramana, 2024).

The sociocultural barriers included the cultural and religious norms and beliefs that may hinder the acceptance and adoption of NIBGM technologies, as well as the socioeconomic disparities in access and affordability of these technologies (Al-Nozha et al., 2022; Alsunaidi et al., 2021; Darwich et al., 2023). On the other hand, the facilitators of NIBGM technologies included the increasing prevalence and burden of diabetes in Saudi Arabia, the growing awareness and interest in these technologies among healthcare providers and patients, and the potential benefits for improving diabetes management and patient outcomes (Acharya et al., 2020; Al-Nozha et al., 2022; Jain et al., 2024).

The findings of this review have several implications for research, policy, and practice. First, future research should focus on addressing the technical challenges and limitations of NIBGM

technologies, such as improving the accuracy, reliability, and interoperability of these technologies, and conducting clinical validation studies to establish their safety and effectiveness for diabetes management (Jain et al., 2024; Xue et al., 2022). Second, policies and guidelines should be developed to support the standardization, regulation, and integration of NIBGM technologies into the Saudi Arabian healthcare system, taking into account the cultural and religious considerations and the socioeconomic disparities in access and affordability (Alsunaidi et al., 2021; Nyiramana, 2024).

Third, practical strategies and interventions should be implemented to enhance the awareness, training, and support for healthcare providers and patients on how to use and interpret NIBGM technologies, as well as to improve the availability and accessibility of these technologies in healthcare settings (Acharya et al., 2020; Asikar, 2024). Moreover, culturally-sensitive and compatible devices and interventions should be designed and implemented to promote the acceptance and adoption of NIBGM technologies among Saudi Arabian patients and healthcare providers, taking into account the cultural and religious norms and beliefs (Al-Nozha et al., 2022; Darwich et al., 2023).

5. Conclusion

In conclusion, this systematic review provides a timely and relevant synthesis of the evidence on the advances, applications, and challenges of NIBGM technologies in the context of Saudi Arabian healthcare. The findings suggest that NIBGM technologies have the potential to improve diabetes management and patient outcomes by offering a painless, convenient, and continuous monitoring of blood glucose levels. However, the adoption and implementation of NIBGM technologies in Saudi Arabia face several barriers and challenges related to technical, organizational, and sociocultural factors.

Future research, policy, and practice should focus on addressing these barriers and challenges, and on developing and implementing culturally-sensitive and compatible devices and interventions to promote the acceptance and adoption of NIBGM technologies among Saudi Arabian patients and healthcare providers. By doing so, NIBGM technologies can contribute to the improvement of diabetes management and the reduction of the burden of diabetes in Saudi Arabia, in line with the national healthcare goals and priorities.

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