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Research Article

Applying the Principles of Sustainability to Diabetes Care in Low Resources Settings: Reduce, Reuse, Recycle

Sama Atta Gitti[1], Saman Sarko Baha Al-den, Zainulabdeen Al-saedi[2]

1 Department of internal medicine, Al-Kindy college of medicine, University of Baghdad, Baghdad, Iraq
2 New York Prespyterian Queens Hospital, NY, United States
* Corresponding author's email: Sama.a@kmc.uobaghdad.edu.iq

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ABSTRACT

Background: Sustainability in healthcare is a relatively new concept that aims to integrate environmental, financial, and social factors. Diabetes care in low socioeconomic communities relies on disposable medical supplies, leading to increased waste. This study aims to propose the application of the (reduce, reuse and recycle) framework in diabetes care to enhance sustainability

Subjects and Methods: This study used a mixed-methods approach, including both a literature review and a pilot survey. The literature review included fifty studies focusing on sustainable healthcare practices. A survey was conducted among fifty healthcare professionals and fifty patients to assess their baseline knowledge about practices related to sustainability in healthcare. Results were analyzed to assess similarities or differences between high and low socioeconomic communities

Results: The survey revealed that 63% of patients thought treatment costs was the primary barrier to sustainability, while 50% of healthcare providers pointed to limited resources. Both groups emphasized the need for government support and education to enhance sustainability efforts. Reusable insulin pens and eco-friendly packaging were the most viable solutions.

Conclusions: Applying sustainability to diabetes care can reduce both environmental and economic burdens. This is particularly challenging in low-resource settings, where cost and infrastructure limitations persist. Policy reforms, education, and innovation to reduce waste is essential to achieve a sustainable healthcare system.

Introduction

Sustainability in healthcare is an evolving concept that aims to integrate the environment's health, equal distribution of resources, and economic stability to build enduring communities for future generations. It is a multidimensional concept that requires a systematic approach to managing current resources in a responsible way for the future [1]. While sustainability is often seen as a modern concept, it is a deeply rooted tradition of Indigenous communities, who have long honored the natural cycles and limits of the environment [2].

In healthcare, sustainability extends beyond financial consideration. It also encompasses the social and environmental responsibilities. The treatment of diabetes involves the frequent use of disposable medical supplies, such as insulin pens, blood glucose monitors, and test strips, which generate substantial waste. This issue is even more pronounced in low-resource communities, where the

environmental burden can further exacerbate the financially strained healthcare system.

The Centre for Sustainable Healthcare has proposed four key principles to reduce healthcare's environmental footprint while maintaining or improving health outcomes: prevention, patient empowerment and self-care, lean pathways, and the use of low-impact technologies [3]. Despite these guidelines, healthcare remains a significant contributor to global carbon emissions, with the sector responsible for 3-10% of national carbon footprints in countries such as Mexico, the UK, and the USA [4].

The financial implications of diabetes care are concerning. The total estimated cost of diagnosed diabetes in 2017 was $327 billion in the USA, including $237 billion in direct medical costs of treatment and investigations and $90 billion in reduced productivity of affected patients [5]. Besides financial costs, the environmental impact of diabetes management, including the disposal of plastic waste from medical supplies, has become an emerging topic of concern [6]. Studies have shown that in diabetes care, the product often represents only a small portion of the total waste generated, with packaging materials accounting for up to 90% of the volume [7]. Diabetes mellitus affects approximately one out of every eleven people worldwide, and the International Diabetes Federation (IDF) predicts that 1.1 million children and adolescents between the ages of 14 and 19 have T1DM [8].

Efforts to address this issue have led to the concept of "green diabetology," which aims to reduce medical waste by encouraging practices such as using reusable insulin pens, optimizing packaging, and recycling medical products [9].

This study aims to explore how the principles of sustainability (reduce, reuse, and recycle) can be applied to diabetes care in low-resource settings such as Iraq, whose healthcare system suffered from multiple crises 10. The role of healthcare facilitators is also highlighted as models for sustainable practices who can promote the adoption of eco-friendly initiatives [11]

Subjects and Methods

This study uses a mixed-methods approach using a literature review and a survey. The systematic review gathered findings from existing literature, while the pilot survey collected data from healthcare professionals to assess practical challenges and opportunities in implementing sustainable diabetes practices.

Regarding the literature review section, Databases including Scopus, PubMed, and Google Scholar were searched for studies on sustainability in diabetes management and its environmental impact. The review included studies from 2013 to 2024. According to PRISMA guidelines, the main points extracted from each study included sustainability initiatives (e.g., reusable insulin pens, eco-friendly packaging), outcomes related to waste reduction, patient empowerment, and cost savings and challenges faced in implementing these initiatives in low-resource settings. At the same time, a pilot survey was distributed to 100 healthcare professionals, including endocrinologists, diabetes educators, and nurses, and 100 diabetic patients who visited outpatient clinics over two months (July–September 2023). The survey questions were grouped into the following categories:

1. Awareness of sustainable healthcare practices and their importance.
2. Challenges in implementing sustainable interventions.
3. Willingness to adopt new technologies like telemedicine and eco-friendly medical devices.

The research team self-developed the survey questionnaire based on a review of the existing literature on sustainable healthcare practices. Two physicians independently reviewed it and pre-tested it on a small group of participants for clarity and relevance.

Data from the literature review and the pilot survey were synthesized through a thematic analysis approach. The literature review provided insight into the theoretical frameworks, which were compared against the survey results, which reflect real-world practices, challenges, and proposed solutions.

Ethical Considerations: The ethics committee of Al-Kindy College of Medicine gave ethical approval. All participants gave informed consent.

Results

PRISMA flow chart

Records were identified through database searching (PubMed, Scopus), and 200 additional records were identified through other sources (e.g., reference lists): 30. After removing duplicates, 180 were screened based on title and abstract. One hundred records were excluded due to irrelevance or studying the wrong population.

Eligibility: Full-text articles assessed for eligibility:80Full-text articles excluded (e.g., irrelevant focus, incomplete data): 30 Studies included in qualitative synthesis: 50

The final PRISMA flow chart summary is summarized in Figure 1.

Ten studies were randomized controlled trials, 15 were cohort studies, and 25 were systematic reviews or meta-analyses.

Most studies (n = 30) involved patients with Type 2 diabetes across various countries, with sample sizes ranging from 500 to 10,000 participants. Ten studies focused specifically on healthcare providers and their role in delivering sustainable care.

Twenty studies evaluated the implementation of sustainable practices in healthcare (e.g., reducing waste and designing energy-efficient hospitals). In contrast, other studies examined the impact of community interventions, such as promoting sustainable diets for diabetes prevention.

Fifteen studies focused on diabetes outcomes (HbA1c control, complication reduction), while 25 studies examined sustainable healthcare interventions' environmental and economic impact.

Thirty studies were conducted in high-income countries (e.g., the U.S., the U.K., and Australia), while 10 studies were conducted in low-resource settings (e.g., sub-Saharan Africa and Southeast Asia).

Studies consistently found that sustainable practices, such as plant-based diets and energy-efficient healthcare practices, positively impacted environmental and patient health outcomes. Table (1) includes a summary of study characteristics.

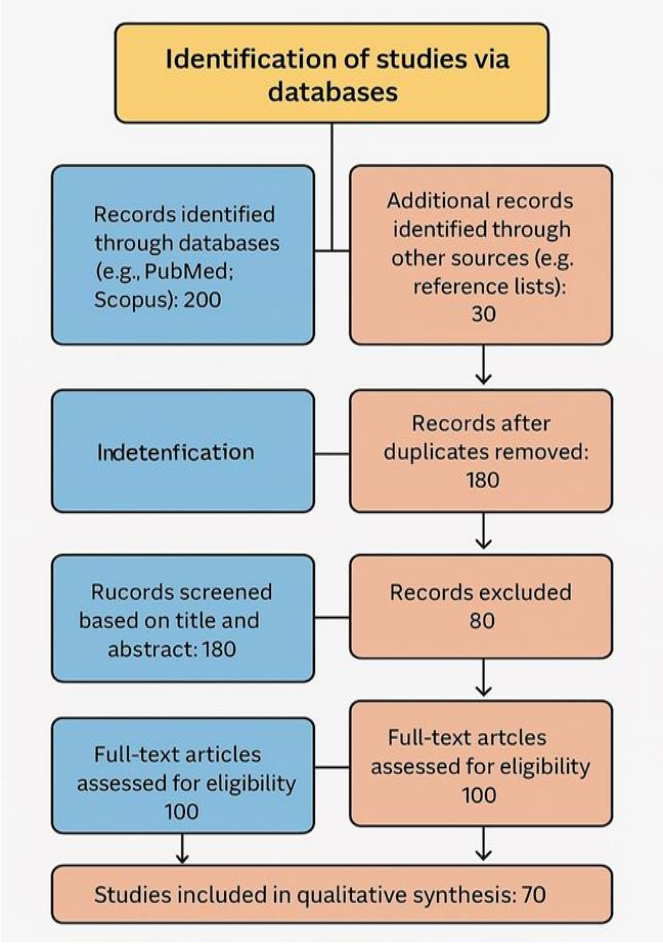

Figure 1: Summary of PRISM flow chart 1

Table 1: Study Characteristics

Characteristic	Details
Study Design	RCT (n=10)
	Cohort (n=15)
	Meta-analyses (n=25)
Population	DM2 patients(n=30)
	Healthcare providers (n=20)
Interventions focus	Sustainable healthcare practices (n=30)
	Community practices (N=20)
Outcomes	Health outcome (n=15)
	Environmental impact (n=25)
Geographical Location	Low resources settings n=30.
Time frame	(2010-2024)
Key Findings	Positive impact on both health outcomes and environmental sustainability.

The review includes 50 studies. They were categorized into three groups based on study design, type of intervention, health outcomes, and population studied. Most of the studies were meta-analyses (n = 25), followed by 15 cohort studies (15) and 10 randomized controlled trials.

Twenty studies focused on healthcare-sustainable practices, such as waste reduction, while 15 studies examined the effect of sustainable nutrition on diabetes control. Most studies took place in high-income countries (n = 30), while twenty in low- and middle-income countries. Summary of categorical grouping of studies is illustrated in table (2) and table (3).

Table 2: categorical grouping of studies

Category	Number of studies
Study design	
RCT	10
Cohort	15
Meta-analyses	25
Type of intervention	
Healthcare	20
Community	15
Environmental	10
Outcome	
DM control	20
Environmental impact	25
Economy	15

The largest age group is 55-65 (45%), followed by 25-35 (32%). The sample was predominantly male (62%). The majority (52%) use oral medication, while 30% use oral medications and insulin, and only 18% are insulin dependent. Most patients get treatment from private pharmacies (57%), while 43% get treatment from governmental centers. Approximately 70% of participants lived in urban areas, while 30% were from rural or semi-urban settings. Regarding the educational background, 28% had completed only primary education, 42% had secondary education, and 30% held a college degree.

A significant proportion (68%) were unaware of the concept of sustainability and its benefits to healthcare. Similarly, 25% were unaware of the environmental benefits. Only 12% have attended formal diabetes care programs, while 85% received basic education from healthcare providers.

The most mentioned challenge was the high monthly cost of treatment (63%), followed by availability issues (22%) and distance (11%).

The most common suggestion (45%) was for the government to provide more treatment options and Continuous Glucose Monitors (CGMs). Educational activities (18%) and more nearby centers (12%) were also important.

The majority of healthcare professionals surveyed were doctors, including 25 specialists and 18 residents. Most professionals (42%) had 10-15 years of experience.

Challenges were limited Resources (50%) and lack of supportive infrastructure (34%) were the most frequently mentioned challenges, followed by lack of Faculty Training (29%).

Regarding awareness, while 59% had read or heard about sustainability, many still lack a deep understanding of how to apply these principles practically in healthcare.

Table 3: Categorization of Studies on Sustainability in Diabetes Care

Category	Study	Focus/Topic	Study Type	Key Findings/Outcome
Sustainability in Healthcare Practices	Aziz et al. (2018)	Integrating sustainability into diabetes care	Systematic Review	Sustainability in diabetes care reduces cost and improves patient outcomes.
	Boulet et al. (2020)	Climate change and respiratory health impact	Observational Study	Climate change indirectly worsens diabetes management.
	Peters et al. (2019)	Addressing diabetes epidemic	Case Study	sustainable practices in healthcare systems are crucial to fight diabetes epidemic.
Sustainable Diets	Augustin et al. (2020)	Use of vegetarian diets for diabetes prevention	Meta-analysis	Plant-based diets lower the risk of type 2 diabetes.
	McCombie et al. (2020)	lifestyle interventions to induce DM remission	Randomized Controlled Trial	Lifestyle sustainable interventions can lead to diabetes remission
Social Determinants and Equity	García-Pérez et al. (2019)	Impact of social determinants on diabetes	Observational Study	Socioeconomic factors influence diabetes outcomes.
	Khunti et al. (2020)	Socioeconomic disparities in diabetes care	Systematic Review	Addressing disparities in diabetes care requires targeted and sustainable health policies.
Economic Impact and Cost-Effectiveness	Bommer et al. (2017)	Global economic burden of diabetes	Economic Analysis	Diabetes-related costs are rising globally; sustainability initiatives can reduce these costs.
	Luo et al. (2020)	Cost-effectiveness of diabetes interventions	Cost-Effectiveness Study	Sustainable diabetes interventions are cost-effective in both short and long-term outcomes.
Technological Interventions	Frier et al. (2020)	Technology in diabetes management	Systematic Review	Technology-driven care improves diabetes management and sustainability.
	Kang et al. (2020)	Impact of technology on glycemic control	Observational Study	Digital tools enhance glycemic control, offering sustainable diabetes solutions.
Environmental Factors and Diabetes	Kolb et al. (2020)	Environmental determinants of type 2 diabetes	Observational Study	Environmental pollution and urbanization contribute to diabetes prevalence.
	Mohammadi et al. (2020)	Built environment's effect on diabetes	Meta-analysis	Walkable, green environments reduce type 2 diabetes risks.
Global and Regional Trends	GBD 2017 Diabetes Collaborators (2019)	Global diabetes burden	Global Health Report	Rising global burden of diabetes necessitates sustainable care models across different regions.
	Gregg et al. (2018)	Global trends in diabetes complications	Systematic Review	Complications of diabetes are increasing globally, demanding sustainable interventions.
Category	Study	Focus/Topic	Study Type	Key Findings/Outcomes
Sustainability in Healthcare Practices	Aziz et al. (2018)	Integrating sustainability into diabetes care	Systematic Review	Sustainability in diabetes care reduces cost and improves patient outcomes.
	Boulet et al. (2020)	Climate change and respiratory health impact	Observational Study	Climate change worsens respiratory conditions, indirectly affecting diabetes management.
	Peters et al. (2019)	Addressing diabetes epidemic	Case Study	Using sustainable practices in healthcare systems is vital for managing the diabetes epidemic.
Social Determinants and Equity	García-Pérez et al. (2019)	Impact of social determinants on diabetes	Observational Study	Socioeconomic factors significantly influence diabetes outcomes.
	Khunti et al. (2020)	Socioeconomic disparities in diabetes care	Systematic Review	disparities in diabetes care requires targeted and sustainable health policies.
Economic Impact and Cost-Effectiveness	Bommer et al. (2017)	Global economic burden of diabetes	Economic Analysis	sustainability initiatives can reduce Diabetes-related costs
	Luo et al. (2020)	Cost-effectiveness of diabetes interventions	Cost-Effectiveness Study	Sustainable diabetes interventions are cost-effective on short and long term.
Technological Interventions	Frier et al. (2020)	Technology in diabetes management	Systematic Review	Technology-driven care improves diabetes management
	Kang et al. (2020)	Impact of technology on glycaemic control	Observational Study	Digital tools enhance glycaemic control in sustainable way.
Environmental Factors and Diabetes	Kolb et al. (2020)	Environmental determinants of type 2 diabetes	Observational Study	Environmental pollution and urbanization contribute to diabetes prevalence.
	Mohammadi et al. (2020)	Built environment's effect on diabetes	Meta-analysis	Walkable, green environments reduce type 2 diabetes risks.
Global and Regional Trends	GBD 2017 Diabetes Collaborators (2019)	Global diabetes burden	Global Health Report	burden of diabetes necessitates sustainable care models
	Gregg et al. (2018)	Global trends in diabetes complications	Systematic Review	Complications of diabetes demand sustainable interventions.

Solutions

Training for Faculty: 20 professionals (29%) believe that faculty training is essential to spread sustainability knowledge.

Government Resources: The most popular solution (50%) involved the government providing sustainable tools, such as Continuous Glucose Monitors (CGMs) and e-records.

Infrastructure Improvements: 34% suggested upgrading waste disposal systems and healthcare infrastructure to facilitate the adoption of sustainable practices.

Integration of systematic review findings with pilot study results

Challenges

Literature: The systematic review identified several barriers to implementing sustainable practices in healthcare, including the high cost of sustainable technologies, lack of governmental support, and limited healthcare infrastructure.

Patients: 63% of patients reported the biggest challenge as the cost of diabetes treatment. Other challenges include the unavailability of some medications (22%), long travel distances to healthcare facilities (11%), and storage problems (4%).

Healthcare Professionals: The primary challenges for professionals are limited resources (50%) and a lack of supportive infrastructure (34%). Of these, 29% mentioned inadequate faculty training.

Integration: Both patients and healthcare professionals pointed to similar problems limiting optimal sustainable care, mainly cost and resource limitations, similar to the challenges outlined in the literature. The financial burden of diabetes care is a major barrier for patients, while professionals see unsupportive infrastructure and limited training as key obstacles. This highlights the need for infrastructural reforms and economic facilities to support sustainable healthcare. These comparisons are summarized in Table 4.

Awareness and Education

Literature: The review advocates for increased education on sustainability in healthcare for healthcare providers and patients.

Patients: Only 12% of patients attended formal diabetes education programs, and 85% reported receiving only basic education from healthcare providers. 68% were unaware of sustainability principles and benefits in healthcare.

Healthcare Professionals: Although 59% were aware of sustainability concepts, only 29% believed that faculty training was sufficient to spread awareness of these principles.

Integration: Both patients and healthcare professionals demonstrated an awareness gap consistent with the literature. This further supports the literature's call for education and awareness campaigns targeting patients and professionals.

Practical Solutions

Literature: The systematic review highlights practical solutions, such as using reusable insulin pens, reducing packaging waste, and improving recycling in healthcare facilities to reduce the environmental footprint and achieve cost savings over time.

Patients: Regarding solutions, 45% of patients suggested that the government should provide more treatment options, including Continuous Glucose Monitors (CGMs); 18% believed that educational activities focused on diet and insulin use would improve care.

Table 4: challenges in implementing sustainability

Source	Challenges for the patient	Challenges for HCP	Challenges in literature
Cost	63% cited the high cost of treatment	50% faced struggles of limited resources due to high expenses	High cost of sustainable technologies
Availability	22% complain from lack of availability of necessary treatments	Limited resources	Lack of infrastructure in low resources countries
Distance	11% suffer from distance to nearby health centre	34% complained from lack of infrastructure	Logistical challenges
Storage	4% suffered from degraded treatment due to lack of necessary storage Environment	Lack of faculty training (29%)	Limited education and institutional support

Table 5: awareness and education of sustainability

Source	Patients	Healthcare Professionals	Literature
General Awareness	68% are unaware of sustainability principles	59% are familiar with sustainability principles	Need for greater sustainability education
Formal Education	Only 12% attended formal diabetes education program or course	29% believe there is lack of faculty training	Education of patients and healthcare providers is essential
Basic Knowledge	85% received basic education from their HCP		Training is essential to widespread adoption

Healthcare Professionals: 50% of professionals thought that the government should supply resources like CGMs and insulin pens, while 29% emphasized the need for training to spread awareness

about sustainability. Infrastructure improvements that focus particularly on waste disposal were mentioned by 34% of respondents.

Integration: Both patients and healthcare professionals align with the literature in calling for governmental support in providing sustainable technologies like CGMs and insulin pens. This mirrors the literature's emphasis on long-term cost savings and reduced waste through reusable medical devices. The need for patient education, identified by both groups, is consistent with the literature's emphasis on sustainability-driven healthcare reforms. Figures 2 and 3 illustrate a summary of the review outcomes and policy suggestions.

Table 6: suggested solutions for sustainable diabetes care

Source	Patients	HCP	Literature
Treatment options	45% want more treatment options such as CGM.	50% suggested more support from government regarding CGM and insulin pens.	Use of reusable insulin pens and ecofriendly packaging.
Educational programs	18% want more education about diet and insulin use.	29% suggested faculty training to improve awareness.	Importance of education to promote sustainability.
Government support	45% want the government to supply more resources.	50% want the government to be more involved.	Government policy and funding.
Infrastructure		34% recommended infrastructure improvement.	Infrastructure development in the form of waste reduction.

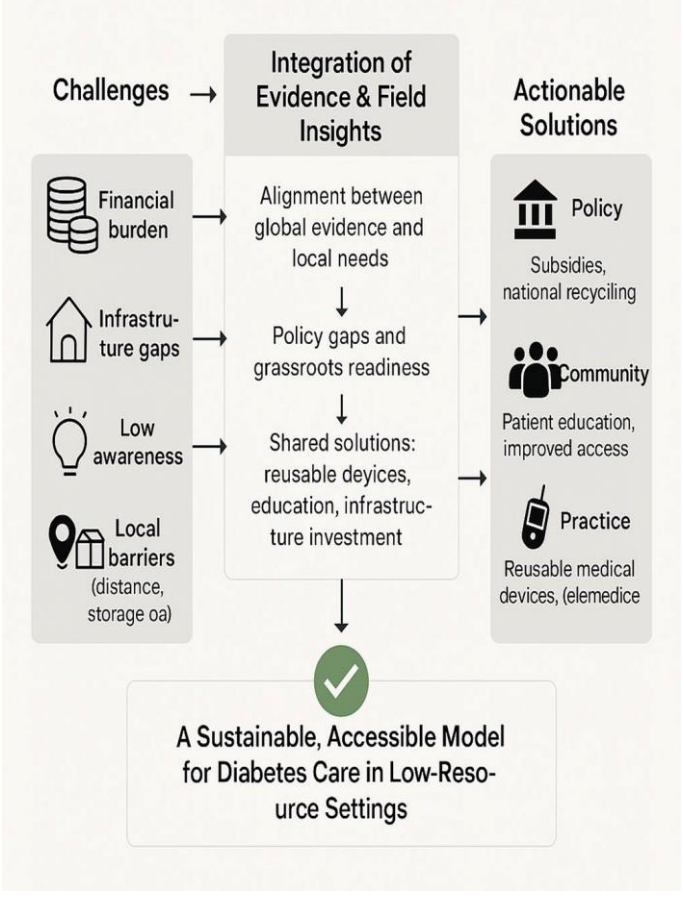

Figure 2: A Conceptual Framework for Implementing Sustainable Diabetes Care in Low-Resource Settings: From Challenges to Actionable Solutions.

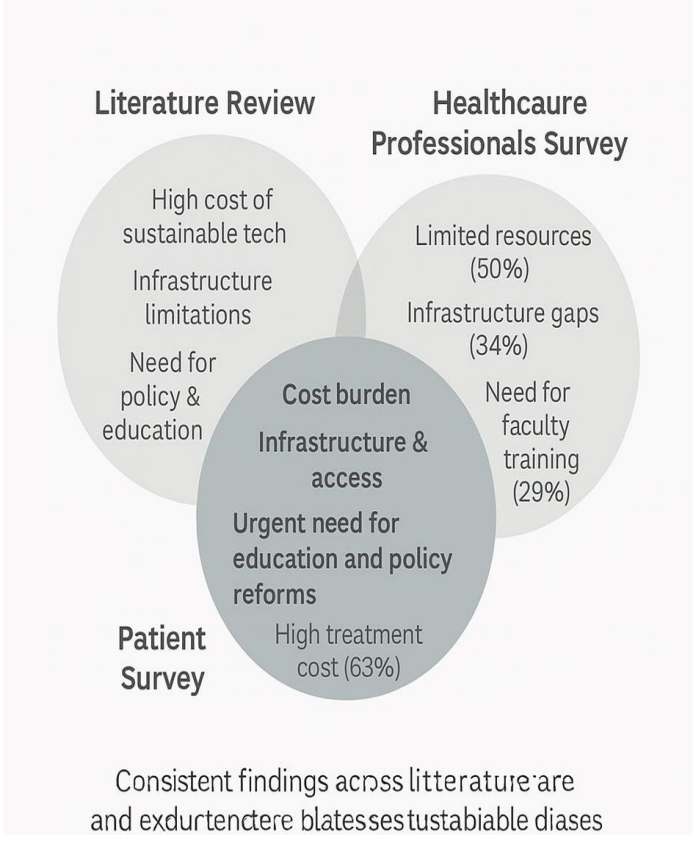

Figure 3: Triangulated Findings from Literature, Patient, and Healthcare Professional Surveys Highlighting Key Barriers and Policy Needs in Sustainable Diabetes Care

Discussion

Applying the 3R framework in Diabetes Care: Reducing Waste, Reusing Resources, and Recycling for a Sustainable Future.

The "Reduce, Reuse, Recycle" framework provides an actionable approach to integrating sustainability into the diabetes healthcare system. Given the significant waste generated by diabetes care, real-world case studies discuss and support each component of the 3R model.

Reduce: Minimizing Waste in Diabetes Care

Reducing waste is fundamental to minimizing the environmental impact of diabetes care, such as plastic and packaging waste generated by essential supplies like blood glucose test strips, CGM systems, and insulin pens [28].

In Germany, diabetes clinics replaced paper information booklets with QR codes on packaging, reducing paper waste by 25%. Patients could access instructions digitally without the need for excessive printed materials. [29].

In the UK, another project switched to biodegradable packaging for insulin pens and test strips and reduced plastic waste by 30% over two years [30]. According to Defruyt, only 2% of plastic packaging is recycled into new materials, with much of it dumped in landfills 29.

Reuse: Promoting Reusable Insulin Pens and Medical Devices

Using reusable devices presents an opportunity for substantial environmental and cost savings.

In Denmark, Novo Nordisk's switch to reusable insulin pens reduced plastic waste by 50%, saving over 80 tons of plastic annually, the equivalent of more than 1.5 million disposable pens. The program also reduced healthcare costs for patients and providers, demonstrating how reusability can benefit both the environment and the healthcare system [31].

The NHS documented that reusable insulin pens significantly save plastic waste and costs. The program reduced the overall carbon footprint by 4.5 kgCO2e per patient, with annual cost savings of up to £22.30 per patient [31].

Recycle: Enhancing Recycling Programs for Medical Waste

Recycling medical waste is essential, but it remains a challenge due to the complexity of medical products. For example, recycling CGM sensors and insulin pumps involves disassembling plastic components and properly disposing of biohazardous materials [32].

A successful initiative in Sweden where patients mailed back used needles, lancets, and CGM components significantly reduced the amount of inappropriately disposed medical waste [30]. Roche also introduced a program to recycle used glucose monitors and infusion sets for future manufacturing 30. Some glucose test strips are now made from biodegradable materials, which can significantly reduce the amount of non-recyclable waste generated by daily testing [30].

Equitable access and distribution

One significant ethical concern is the fair distribution of sustainable healthcare technologies, such as reusable insulin pens or biodegradable medical products. While these innovations can reduce environmental harm and lower costs in the long run, they may not be affordable or readily available to all patients, particularly in low—and middle-income countries. To address this, governments and health organizations should ensure equitable access to environmentally friendly medical products for low-income patients.

Rural communities and individuals with lower socioeconomic status often face barriers to healthcare facilities. For example, reducing packaging waste or switching to reusable devices may be environmentally beneficial but unavailable in low-resource communities [33].

A significant difference is noted between high- and low-resource settings in terms of sustainable diabetes care. While studies from high-income countries mention reusable insulin pens, biodegradable packaging, and governmental policies to reduce waste, these solutions are largely inaccessible in low-income regions.

Comparison Between Low-Resource and High-Resource Settings

There is a notable difference between high- and low-resource settings regarding the implementation of sustainable healthcare. Switching to reusable insulin pens resulted in 80 tons of waste reduction annually, [34]. Similarly, a study from the Netherlands documented the successful use of recycling systems to segregate waste [35]. This success is contrasted by the results of a survey from sub-Saharan Africa, which reported that lack of infrastructure and insufficient training were the main barriers to sustainable healthcare [36,37,38]. These disparities underscore the urgent need to adopt practical, sustainable solutions in resource-limited areas and highlight the fact that effective solutions in high-income communities cannot be simply imported without practical modifications.

Limitations

Financial obstacles faced by healthcare systems in these regions. The adoption of reusable medical devices or the development of waste management systems requires initial investment. This financial barrier often leads to a focus on short-term, cost-effective solutions rather than long-term sustainability strategies.

Lack of infrastructure to support sustainable practices. Many healthcare facilities in low-resource settings lack proper waste disposal systems, limited access to sustainable medical products, such as reusable insulin pens and face logistical challenges, such as

unreliable electricity or water supply that is used in sustainable efficient power supply.

Educational barriers also play a role in limiting the application of these principles. Many healthcare workers and patients lack awareness of the environmental impact of certain medical practices or may not be trained in using sustainable alternatives.

Lack of Inferential Statistical Analysis: This study is a pilot study with exploration nature and small sample size; therefore, descriptive statistics were used to interpret the results. Future studies with larger sample and statistical comparisons between subgroups are recommended.

Conclusion

Applying the (Reduce, Reuse, Recycle) framework, along with eco-friendly technologies (illustrated in Figure 4), can significantly lower healthcare's environmental impact. The key ethical challenge is ensuring these benefits are accessible to all communities, including low-income and rural areas.

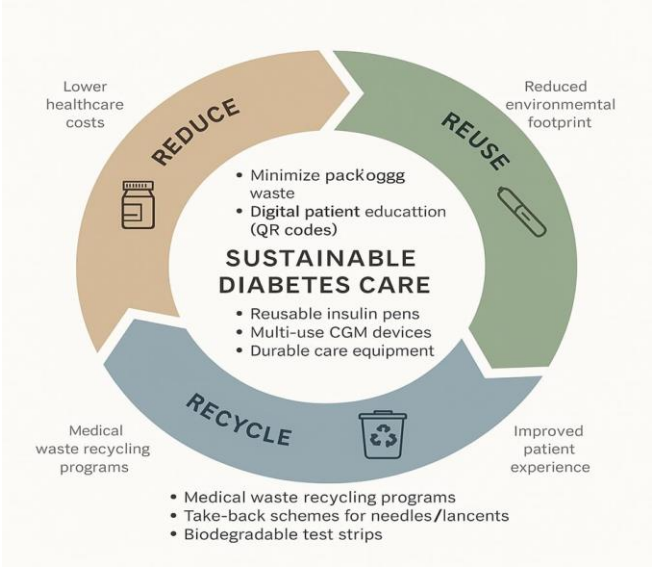

Figure 4: A Circular Framework for Integrating the 3Rs (Reduce, Reuse, Recycle) into Sustainable Diabetes Care

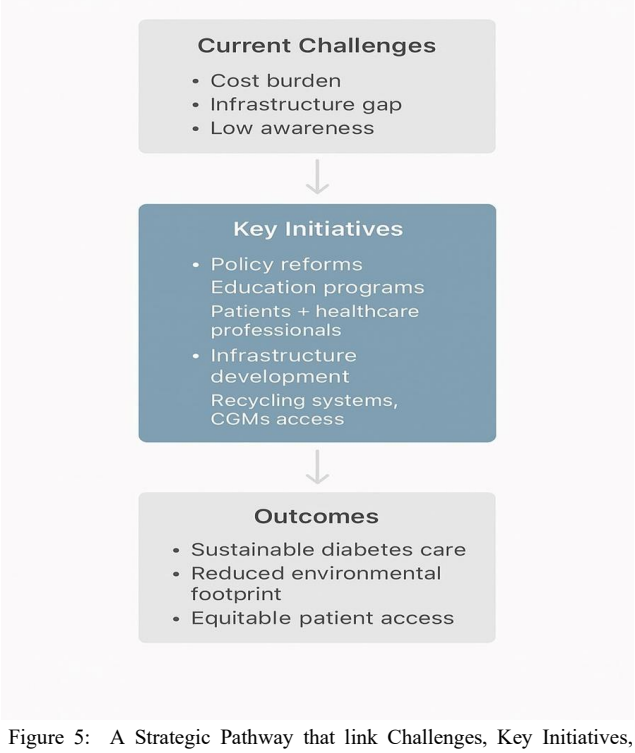

Figure 5: A Strategic Pathway that link Challenges, Key Initiatives, and Outcomes for Achieving Sustainable Diabetes Care

Recommendations

There are practical solutions that can be applied in low-resource settings such as the use of national recycling programs for medical waste.

Localized manufacturing of biodegradable medical products could reduce both environmental impact and cost.

Mobile health technologies that reduce the need for physical infrastructure, enabling healthcare delivery that minimizes resource use while reaching underserved populations.

Governments and international organizations need to prioritize sustainability in healthcare in terms of funding and infrastructure development. As illustrated in Figure (5), addressing current healthcare challenges through key initiatives, such as policy reforms, improvement of infrastructure, and education, can eventually achieve more sustainable diabetes care.

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Conflict of Interest

Authors declare no conflict of interest.

Data availability

Data are available upon reasonable request.

ORCID

Sama Gitti 0000-0003-0117-163X
Saman Baha Al-den 0000-0003-4240-7151
Zainulabdeen Al-saedi 0000-0002-0978-5655

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