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CONTINUOUS GLUCOSE MONITORING IN DIABETES MANAGEMENT: CLINICAL BENEFITS AND THE ROLE OF FREESTYLE LIBRE

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ABSTRACT

Diabetes poses a significant public health challenge and requires effective methods for monitoring and managing glucose levels. Traditional approaches, such as glycated hemoglobin (HbA1c) and self-monitoring of blood glucose (SMBG), have important limitations, including a limited ability to assess glycemic variability and detect hypoglycemic episodes. This study aims to present the development of continuous glucose monitoring (CGM) technologies, evaluate their impact on metabolic control and patients' quality of life, and analyze the role of the FreeStyle Libre system in modern diabetes care. This literature review is based on an analysis of randomized controlled trials, observational studies, and clinical guidelines regarding CGM use. Real-world data and recent evidence on the development of diabetes technologies were also included. The findings indicate that CGM use is associated with improved glycemic control, including reduced HbA1c levels, increased time in range (TIR), and fewer hypoglycemic episodes. The FreeStyle Libre system, as an example of flash glucose monitoring technology, is particularly effective in reducing hypoglycemia, while real-world data suggest additional improvements in HbA1c levels. In summary, CGM represents a key component of modern diabetes care, enabling a more precise and personalized approach to treatment and supporting the digital transformation of healthcare.

KEYWORDS

Continuous Glucose Monitoring, FreeStyle Libre, Flash Glucose Monitoring, Time in Range (TIR), Hypoglycemia, Glycemic Control

CITATION

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1. Introduction

Diabetes is one of the most serious public health challenges worldwide, and its prevalence continues to increase. According to data from the World Health Organization, the disease remains one of the leading causes of cardiovascular complications, kidney failure, and vision loss, placing a significant burden on healthcare systems [1]. Effective glycemic control plays a key role in reducing the risk of complications and improving clinical outcomes in people with diabetes.

Traditionally, glycemic control has been assessed using glycated hemoglobin (HbA1c) and self-monitoring of blood glucose (SMBG). Despite their widespread use, these methods have significant limitations. HbA1c reflects average glucose levels but does not account for glycemic variability or the occurrence of hypoglycemic and hyperglycemic episodes, whereas SMBG provides only intermittent measurements and may not detect hypoglycemic episodes, including asymptomatic ones [2,3,4]. These limitations hinder a comprehensive assessment of metabolic control and the optimization of therapy.

In response to these limitations, continuous glucose monitoring (CGM) systems have been developed, enabling real-time or continuous measurement of glucose levels and analysis of glycemic trends and variability. Clinical trials and meta-analyses have demonstrated that CGM use is associated with improved glycemic control, including reduced HbA1c, increased Time in Range (TIR), and reduced time spent in hypoglycemia [5,6]. CGM also enables more precise treatment adjustment and supports a data-driven approach to diabetes management.

Advances in CGM technology have led to the introduction of new metrics for assessing glycemic control. One of the most important is Time in Range (TIR), defined as the percentage of time during which glucose levels remain within the target range. This parameter complements HbA1c and allows for a more comprehensive assessment of glycemic variability and exposure to hypoglycemic and hyperglycemic episodes [3].

Technological progress in diabetes care includes not only the development of monitoring systems but also their integration with digital tools, such as mobile applications, telemedicine platforms, and automated insulin delivery (AID) systems. According to the American Diabetes Association guidelines, these technologies play an increasingly important role in personalizing therapy and supporting clinical decision-making [7].

Flash glucose monitoring (FGM) systems, such as FreeStyle Libre, represent an important step in the evolution of glucose monitoring technologies, enabling the transition from intermittent measurements to systems providing real-time or near real-time data. Their ease of use and accessibility have contributed to their widespread adoption in clinical practice and increased patient engagement in diabetes management [8].

Despite the growing body of evidence supporting CGM, further research is needed to better understand its impact on various aspects of patient care, including quality of life and its use in routine clinical practice.

The aim of this study is to present the development of continuous glucose monitoring technologies, assess their impact on metabolic control and patients' quality of life, and analyze the role of the FreeStyle Libre system in the context of modern clinical practice and the digital transformation of diabetes care.

2. Methods

This study presents a narrative review of the literature on continuous glucose monitoring (CGM) systems, including the FreeStyle Libre system, in diabetes management. A literature search was conducted using electronic databases such as PubMed, Google Scholar, and Web of Science. The search strategy included combinations of keywords such as "continuous glucose monitoring," "CGM," "flash glucose monitoring," "FreeStyle Libre," "Time in Range," and "hypoglycemia." The review primarily included publications from 2016 to 2025, with particular emphasis on recent high-quality studies. The initial selection of articles was based on the analysis of titles, keywords, and abstracts. Publications not directly related to glucose monitoring or lacking clinical relevance were excluded. Subsequently, a detailed review of the full texts of articles meeting the inclusion criteria was conducted. The review included randomized controlled trials, observational studies, meta-analyses, clinical guidelines, and real-world evidence studies. Only publications in English with full texts or sufficiently detailed abstracts were included to allow assessment of their relevance. Preclinical studies, in vitro models, and publications of limited methodological quality were excluded. Articles were selected based on their relevance to the study objective, scientific value, and usefulness in evaluating the effectiveness and application of CGM systems. Particular attention was given to outcomes related to glycemic control, including glycated hemoglobin (HbA1c) levels, Time in Range (TIR), and the incidence of hypoglycemic episodes.

3. Development of Continuous Glucose Monitoring Technologies

Evolution of Glucose Monitoring

Glucose monitoring is a fundamental component of diabetes management and a key tool for assessing metabolic control. For many years, self-monitoring of blood glucose (SMBG) remained the primary method, enabling intermittent assessment of glucose levels and supporting therapeutic decision-making.

Advances in medical technology have led to the introduction of continuous glucose monitoring (CGM) systems, which provide continuous access to glucose data and allow for the analysis of glycemic trends and variability. Compared to traditional methods, CGM provides a more detailed and dynamic picture of glycemic patterns [9].

The introduction of CGM has also enabled the development of new indicators for assessing glycemic control. One of the key parameters is Time in Range (TIR), defined as the percentage of time spent within the target glucose range. This parameter is an important complement to glycated hemoglobin (HbA1c) and allows for a more detailed assessment of glycemic variability and exposure to episodes of hypo- and hyperglycemia [3].

The development of glucose monitoring technology reflects a broader trend toward the digitization of healthcare and the advancement of personalized medicine, in which real-time data play an increasingly important role in therapeutic decision-making.

Self-Monitoring of Blood Glucose versus Continuous Glucose Monitoring

Glycated hemoglobin (HbA1c) and self-monitoring of blood glucose (SMBG) are among the primary methods for assessing glycemic control; however, they do not allow accurate assessment of glycemic variability throughout the day. These methods may also fail to detect episodes of hypo- and hyperglycemia occurring outside standard measurement times [4]. In particular, hypoglycemic episodes, especially during the night, may remain undetected with intermittent measurements [3].

HbA1c primarily reflects average glucose levels and does not provide information on glycemic excursions or variability, which limits its usefulness in a comprehensive assessment of metabolic control [2]. Additionally, HbA1c levels may be influenced by factors not directly related to blood glucose.

In response to these limitations, CGM systems were developed, providing continuous glucose data and enabling the analysis of glycemic trends and fluctuations over time, allowing for a more comprehensive assessment of metabolic control [9].

Clinical studies have demonstrated that the use of CGM is associated with improved glycemic control. In randomized clinical trials, a statistically significant reduction in HbA1c levels has been observed in patients using CGM compared with SMBG [5,10]. A meta-analysis of randomized trials has also confirmed the effectiveness of CGM in reducing HbA1c levels [6].

In addition to its impact on HbA1c, CGM enables the assessment of TIR, which is an important complement to traditional indicators of metabolic control [3].

Additionally, CGM systems can generate alerts warning of hypo- and hyperglycemia, allowing for rapid response and improved patient safety. As a result, CGM represents a more advanced and comprehensive tool for glucose monitoring than SMBG.

Technological Advances in CGM Systems

The development of CGM systems in recent years has led to significant improvements in their accuracy. This progress is the result of continuous technological innovation, including improvements in sensor design, the development of enzymatic biosensors and electrode materials, and increased biocompatibility of measurement systems. Modern CGM systems demonstrate high measurement accuracy and stability, resulting from advances in sensor technology [11].

One of the key parameters used to assess CGM accuracy is the MARD (Mean Absolute Relative Difference) index. With technological progress, a gradual decrease in this index has been observed, and modern systems achieve values below 10%, indicating high agreement with reference methods [12].

Clinical studies indicate that the accuracy of modern systems remains stable throughout the entire sensor wear time. In next-generation systems, more than 90% of results fall within acceptable error limits [13]. At the same time, sensor wear time has been extended to approximately 14 days.

A key area of development has been reducing the need for calibration. Modern factory-calibrated systems eliminate the need for routine fingerstick calibration, which simplifies use and increases acceptance of this technology [14].

The development of CGM also includes integration with digital systems and real-time data analysis, enabling the identification of glycemic patterns and supporting therapeutic decision-making [15]. Systems that automate treatment based on predictive algorithms are also becoming increasingly important [16].

4. Clinical Benefits of Continuous Glucose Monitoring

Effects on HbA1c

Meta-analyses of comparative studies indicate that the use of CGM systems is associated with improved metabolic control compared with self-monitoring of blood glucose (SMBG). In patients with type 2 diabetes, a reduction in glycated hemoglobin (HbA1c) levels has been observed [17].

The reduction in HbA1c associated with CGM use is moderate but remains statistically and clinically significant. Systematic reviews have demonstrated an average reduction in HbA1c of approximately 0.25–0.32% compared with SMBG [17,18], confirming the consistency of this effect. Although the observed changes are modest in magnitude, their clinical significance remains substantial, particularly in the context of reducing the risk of complications and enabling more precise treatment adjustment through continuous access to glucose data.

Furthermore, CGM use is associated not only with reductions in HbA1c but also with improved glycemic stability and reduced glycemic variability compared with SMBG. In a randomized clinical trial conducted in patients with type 1 diabetes, a significant reduction in glycemic variability was observed in those using CGM [19].

Impact on Hypoglycemia

Hypoglycemia represents one of the main barriers to intensifying diabetes treatment and is a key factor influencing the choice of therapeutic strategy. In patients with long-standing diabetes, impaired hypoglycemia awareness may develop, increasing the risk of severe complications. In older adults, hypoglycemia is additionally associated with an increased risk of clinical complications and adverse events.

Compared with self-monitoring of blood glucose (SMBG), continuous glucose monitoring (CGM) systems provide a more comprehensive assessment of the glycemic profile and significantly reduce time spent in hypoglycemia [5].

Hypoglycemic episodes may remain unrecognized by patients, which further increases the risk of complications. Studies have shown that CGM use leads to a significant reduction in time spent in hypoglycemia, including during nighttime hours [5,20].

The use of CGM systems equipped with alarm functions allows for early detection of dangerous drops in glucose levels and the implementation of appropriate preventive measures. As a result, this technology contributes to improved patient safety and a reduced risk of hypoglycemia [20].

Time in Range as a Glycemic Metric

The limitations of traditional glycemic control indicators and the need for a more comprehensive assessment of the glycemic profile have led to increasing interest in CGM-based parameters such as Time in Range (TIR).

Time in Range (TIR) is a metric derived from continuous glucose monitoring (CGM) data that refers to the percentage of time during which glucose levels remain within the target range, typically 70–180 mg/dL. TIR assessment is possible due to CGM systems, which provide continuous glucose measurements, enabling evaluation of time spent in specific glycemic ranges, including hypoglycemia and hyperglycemia [3,4].

Analysis of CGM data indicates that the relationship between HbA1c and TIR is not straightforward, and patients with similar HbA1c levels may differ significantly in terms of TIR values [2].

According to international consensus on CGM data interpretation, maintaining a TIR above 70% is recommended for most adults with diabetes. At the same time, time spent below 70 mg/dL should be <4%, below 54 mg/dL <1%, and time above 180 mg/dL <25% [3].

In clinical practice, TIR provides a more comprehensive assessment of glycemic control than HbA1c, as it reflects both average glucose levels and glycemic variability. Consequently, it is considered one of the key parameters in CGM data interpretation [3,4].

Time in Range and Risk of Diabetes Complications

A growing body of evidence indicates that time in range (TIR) is not only an indicator of current glycemic control but also a parameter significantly associated with the risk of developing diabetes complications. Higher TIR values are associated with a lower risk of microvascular complications, such as diabetic retinopathy and nephropathy.

Analyses based on data from the DCCT study have shown that every 10% decrease in TIR is associated with an approximately 64% increase in the risk of diabetic retinopathy progression and an approximately 40% increase in the risk of microalbuminuria [21]. These findings indicate a strong inverse relationship between TIR and the risk of microvascular complications.

Similar relationships have been observed in other studies, which demonstrated a clear inverse correlation between TIR values and the presence and severity of diabetic retinopathy. Lower TIR values were associated with a higher prevalence of the condition and a more severe disease course [22].

This relationship may be explained by the fact that TIR reflects not only average glucose levels but also exposure to episodes of hypo- and hyperglycemia, which play an important role in the pathogenesis of diabetes complications [4].

Consequently, TIR is currently recognized as a clinically useful indicator that complements HbA1c in assessing the risk of long-term complications and supports therapeutic decision-making [3,21].

Continuous glucose monitoring systems represent a modern and comprehensive tool for assessing metabolic control, extending beyond traditional indicators such as HbA1c. They enable continuous assessment of the glycemic profile, reduction of hypoglycemic episodes, and analysis of parameters such as TIR, contributing to improved clinical outcomes and supporting a more personalized approach to diabetes management.

5. Impact of CGM and Quality of Life of Patients

Patient Comfort and Daily Functioning

The use of CGM systems can improve the quality of life in people with diabetes. Unlike traditional self-monitoring of blood glucose (SMBG), CGM reduces the need for repeated fingerstick testing, resulting in less discomfort and greater convenience in daily functioning.

Access to continuous glucose data enables more informed therapeutic decisions and better planning of daily activities, including meals, physical activity, and insulin therapy. Increased access to information promotes greater patient autonomy and enhances the sense of control over the disease.

The use of CGM systems is associated with improvements in patients' quality of life, including greater treatment satisfaction, reduced frequency of hypoglycemia, and decreased work absenteeism, while maintaining HbA1c levels [23].

Reduction of Hypoglycemia-Related Stress

Fear of hypoglycemia is one of the key factors affecting the quality of life of patients with diabetes. The use of continuous glucose monitoring (CGM) systems, especially those equipped with alarm functions, can increase the sense of safety, improve glycemic control, and reduce the risk of hypoglycemic episodes [20].

The ability to monitor glucose levels in real time and receive alerts about abnormal values allows patients to respond promptly and may reduce fear of hypoglycemia.

Patient Education and Self-Management

CGM systems play a significant role in patient education, enabling a better understanding of the relationship between lifestyle, treatment, and changes in glucose levels. Access to real-time data promotes more informed treatment decisions and increases patient engagement in the management of their condition [24].

A randomized clinical trial demonstrated that combining CGM use with structured education results in significantly better clinical outcomes than CGM use alone, including increased time in range (TIR) and improved glycemic control [25].

It is emphasized that the effectiveness of CGM systems largely depends on appropriate patient education and the ability to interpret data and adjust therapy accordingly. This may translate into improved glycemic control and a reduction in the duration of hypoglycemic episodes.

The use of CGM affects not only clinical parameters but also patients' daily functioning, independence, and perceived quality of life.

6. The FreeStyle Libre System

Technological Characteristics

FreeStyle Libre is a flash glucose monitoring (FGM) system that enables continuous measurement of glucose levels in interstitial fluid using a sensor placed in subcutaneous tissue. This method is associated with a slight delay compared with blood glucose levels, particularly during periods of rapid glycemic changes [8].

In earlier generations of the system, data reading required the user to actively scan the sensor, which was a characteristic feature of FGM systems and distinguished them from conventional continuous glucose monitoring (CGM) systems.

Data generated by glucose monitoring systems allow for the analysis of glycemic patterns and support therapeutic decision-making [7].

Modern generations of the system are characterized by high measurement accuracy, reflected in mean absolute relative difference (MARD) values below 10% [13]. It should be emphasized, however, that with the development of subsequent generations, the method of data transmission has undergone significant changes.

Evolution of the FreeStyle Libre System

The development of subsequent generations of the FreeStyle Libre system has led to significant changes in functionality and data transmission methods. The first generation (FreeStyle Libre 1) required active scanning of the sensor to obtain data and was not equipped with alarm functions.

Clinical trials demonstrated that the use of this generation resulted in a significant reduction in time spent in hypoglycemia, without a significant improvement in HbA1c levels [26].

The next generation (FreeStyle Libre 2) introduced alarm functions, enabling early detection of hypoglycemia and hyperglycemia. Randomized trials in pediatric populations demonstrated a significant reduction in time spent below the target range [27]. Despite the introduction of alarms, the system still required active scanning to obtain current glucose readings.

The most advanced generation (FreeStyle Libre 3 and Libre 3 Plus) enables automatic real-time data transmission without the need for active sensor scanning. This solution makes the system functionally similar to conventional CGM systems, increasing data availability and improving treatment safety [13].

The technological advancement of the system reflects a broader trend in diabetes care toward increasing the availability of real-time data, improving measurement accuracy, and integrating glucose monitoring systems with modern therapeutic solutions.

Clinical Effectiveness of FreeStyle Libre

Randomized Clinical Trials

Randomized clinical trials are a key source of evidence regarding the effectiveness of the FreeStyle Libre system.

The IMPACT study demonstrated that the use of the system in patients with type 1 diabetes leads to a significant reduction in time spent in hypoglycemia by approximately 38%, without increasing the risk of adverse events [28].

In the REPLACE study, which included patients with type 2 diabetes treated with insulin, no significant change in HbA1c levels was observed; however, a significant reduction in the duration of hypoglycemia was noted, particularly during nighttime hours [26].

A randomized clinical trial in children with type 1 diabetes demonstrated that the use of the FreeStyle Libre 2 system leads to a significant reduction in time spent below the target range, despite no significant change in HbA1c levels [27].

Overall, available randomized studies indicate that the FreeStyle Libre system primarily reduces episodes of hypoglycemia and improves treatment safety, while its effect on HbA1c under controlled conditions remains limited.

Real-World Evidence

Real-world evidence studies provide an important complement to data from randomized trials, allowing for the assessment of the system's effectiveness in routine clinical practice.

An analysis involving a very large number of measurements demonstrated that a higher frequency of sensor scanning is associated with lower HbA1c levels, increased time in range (TIR), and reduced time spent in hypoglycemia [29].

Observational studies have also confirmed improved glycemic control and quality of life in patients using the FreeStyle Libre system [23]. These findings were further supported by a meta-analysis including both observational and randomized studies, which demonstrated a significant reduction in HbA1c [30].

In contrast to randomized trials, real-world data indicate a significant improvement in HbA1c levels, which may result from longer observation periods, greater population heterogeneity, and the influence of user behaviors, such as more frequent glucose monitoring and treatment adjustments based on the data obtained.

Taken together, these findings suggest that the effectiveness of the FreeStyle Libre system in improving glycemic control, including HbA1c reduction, is most evident in real-world clinical settings.

FreeStyle Libre in Clinical Practice

The FreeStyle Libre system is widely available in many countries, and its inclusion in reimbursement programs for selected patient populations across various healthcare systems has contributed to increased use in clinical practice [23].

A key advantage of the system is its ease of use, resulting from the lack of calibration requirements and convenient access to glucose data. These features support its use in routine clinical practice [8,31].

The system is widely used in patients with both type 1 and type 2 diabetes. Studies have shown that its use is associated with reduced time spent in hypoglycemia and improvements in selected parameters of glycemic control [26,28,30].

FreeStyle Libre represents a technology that has transformed glucose monitoring toward a data-driven, real-time model, supporting therapeutic decision-making and aligning with the digital transformation of diabetes care.

7. Digital Transformation in Diabetes Care

Telemedicine and Remote Monitoring

The integration of data from CGM systems with telemedicine tools enables remote patient monitoring, analysis of glycemic profiles, and supports clinical decision-making, contributing to more effective and personalized diabetes management [32].

The use of telemedicine in diabetes care is associated with improved glycemic control and increased access to healthcare services [33]. Telemedicine solutions enable remote patient care, which is particularly important in situations where access to in-person visits is limited and aligns with the development of modern healthcare delivery models.

The importance of telemedicine in diabetes care has increased significantly during the COVID-19 pandemic, when remote care was widely implemented in the management of patients with diabetes [34].

Studies indicate that telemedicine solutions were well accepted by patients and served as an essential tool for maintaining continuity of care.

Mobile Applications and Patient Engagement

Mobile applications are a key component of modern diabetes care, providing access to health data and supporting disease management in daily life. The American Diabetes Association guidelines emphasize that advances in diabetes technology include not only medical devices but also software and digital tools that support monitoring and treatment.

In the context of CGM systems, mobile applications provide patients with real-time access to glucose levels, glycemic trends, and historical data. Access to this information supports daily disease management and facilitates the interpretation of changes in glucose levels [7].

The literature indicates that mobile applications can support diabetes self-management; however, their effectiveness depends on the level of patient engagement and support from healthcare professionals [35].

Mobile applications and digital platforms also enable the sharing of glycemic data with the healthcare team. Studies on the use of CGM systems in remote care have shown that such data can be used to monitor patient status during telemedicine consultations [36].

Mobile tools may increase patient engagement in the treatment process; however, their effectiveness depends on the quality of implementation and their adaptation to individual user needs [35].

Data Analysis and Emerging Technologies in CGM-Based Diabetes Management

Visualization of CGM data, including the use of standardized reports such as the ambulatory glucose profile (AGP), facilitates the interpretation of results and is recommended as a standard method for presenting and analyzing glycemic data [3].

In recent years, there has been growing interest in the use of artificial intelligence (AI) in the analysis of diabetes-related data. Literature reviews indicate that machine learning algorithms can support the analysis and interpretation of glycemic data, including glucose level prediction and detection of glycemic events, and may serve as tools supporting clinical decision-making in diabetes management [37]. Despite promising results, the clinical application of artificial intelligence in diabetes care still requires further research and validation.

In addition, automated insulin delivery (AID) systems are being developed that use CGM data to adjust insulin delivery in real time. These systems integrate glucose measurements with control algorithms, which may contribute to improved metabolic control and reduced risk of hypoglycemia [7].

Consequently, the analysis of CGM data and the development of tools supporting clinical decision-making represent one of the key directions in the advancement of modern diabetes care. The integration of advanced data analytics, artificial intelligence, and automated insulin delivery systems enables an increasingly personalized and data-driven approach to the treatment of patients with diabetes.

8. Limitations and Challenges of Continuous Glucose Monitoring

Despite the numerous benefits of continuous glucose monitoring (CGM) systems, their use in clinical practice is associated with several important limitations. One of the main challenges remains the high costs related to device acquisition and ongoing sensor use, which may limit the accessibility of this technology for some patients. Access to CGM varies depending on the country and healthcare system, and reimbursement does not always cover all patients requiring intensive glucose monitoring. Financial and systemic constraints may therefore contribute to inequalities in access to modern diabetes technologies [7].

Barriers related to the use of this technology also represent a significant limitation, including the need for patients to correctly operate devices and interpret the data obtained. The use of CGM requires adequate patient education and engagement, and at the same time, the analysis of large amounts of glucose data may be challenging in everyday disease management [3].

The effectiveness of CGM depends strongly on consistent use, and interruptions in its use may reduce its impact on glycemic control. As digital technologies continue to evolve, additional challenges related to system integration and data management also emerge [7].

Despite technological advances, technical issues such as limitations in measurement accuracy, potential signal loss, and the need for regular sensor replacement continue to pose challenges in the daily use of CGM systems.

Conclusions

Digital technologies play a significant and growing role in modern diabetes care. These technologies improve the accuracy of monitoring and support clinical decision-making. Combined with data analysis and digital solutions, continuous glucose monitoring systems enable continuous assessment of metabolic trends and a more personalized approach to treatment.

A review of existing studies suggests that the use of CGM in clinical practice, as demonstrated by the FreeStyle Libre system, is associated with improved glycemic control, enhanced treatment safety, and increased patient engagement. These technologies also promote data-driven and patient-centered models of care.

Despite the numerous benefits, fully realizing the potential of CGM requires further research on its long-term health outcomes, cost-effectiveness, and integration with artificial intelligence and telemedicine systems. Reducing disparities in access to these technologies and developing consistent, clinically validated models for their implementation across different healthcare systems remain important priorities in future research and practice.

This review has certain limitations, including reliance on published data and the heterogeneity of included studies.

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