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Long-Term Benefits of Continuous Glucose Monitoring Combined with Insulin Pump Therapy

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ABSTRACT

Objective: To evaluate the long-term efficacy and safety of continuous glucose monitoring (CGM) combined with insulin pump therapy, focusing on glycemic control, patient adherence, quality of life, and reduction in diabetes-related complications. **Methodology:** A prospective cohort study was conducted on 100 patients with type 1 or insulin-dependent type 2 diabetes from February 2023 to July 2024 at a Tertiary Care Hospital in Karachi. Participants, aged 18–75 years, used CGM-integrated insulin pump therapy. Key metrics included HbA1c levels, time-in-range (TIR), adherence rates, and quality-of-life scores assessed at baseline and study completion. Statistical analyses were performed using SPSS, with significance set at $p < 0.05$. **Results:** The mean HbA1c level decreased to 8.14% (SD: 0.83, $p = 0.003$), while TIR improved to 67.90% (SD: 12.57, $p = 0.001$). Adherence rates were high, averaging 89.81% (SD: 5.62, $p = 0.02$), reflecting strong patient engagement. Quality-of-life scores also increased significantly, with a mean score of 79.74 (SD: 11.28, $p = 0.015$). No severe adverse events were reported, underscoring the safety of the intervention. **Conclusion:** CGM combined with insulin pump therapy significantly improves long-term glycemic control, adherence, and quality of life in diabetes management. These findings highlight the clinical and psychosocial benefits of integrating these technologies, particularly in achieving sustainable outcomes. Future research should explore broader population impacts, cost-effectiveness, and advanced technological integration. .

INTRODUCTION

Diabetes mellitus, a chronic metabolic disorder characterized by persistent hyperglycemia, presents a significant global health challenge. Effective management of diabetes, particularly type 1 diabetes (T1D) and insulin-dependent type 2 diabetes (T2D), requires precise glycemic control to mitigate long-term complications. CGM and insulin pump therapy have emerged as transformative tools in diabetes management, offering real-time glucose tracking and automated insulin delivery. These advancements mark a significant shift from traditional self-monitoring and multiple daily insulin injections (MDI), which often fail to provide optimal glycemic outcomes.[1,2]

The evolution of CGM technology has been pivotal in diabetes care, providing granular data on glucose variability and enabling proactive adjustments to therapy. CGM integrated with insulin pump therapy, commonly referred to as sensor-augmented pump (SAP) therapy, demonstrates superior efficacy in improving glycemic metrics compared to standalone insulin pumps or CGM.[3,4] SAP therapy has demonstrated consistent benefits in glycemic outcomes, particularly in reducing glycemic variability, which is a critical factor in mitigating both microvascular and macrovascular complications.[5]

Globally, the adoption of CGM and insulin pump therapy has varied, with notable regional disparities influenced by healthcare infrastructure and socioeconomic factors. For instance, long-term data from China show that continuous subcutaneous insulin infusion (CSII) therapy outperforms MDI in achieving glycemic targets and improving time in range (TIR).[6] In South Asia, where diabetes prevalence is among the highest worldwide, access to advanced diabetes technologies remains limited. This context underscores the importance of evaluating these therapies' long-term outcomes in diverse populations.[7,8]

CGM combined with insulin pump therapy has shown sustained improvements in HbA1c levels, TIR, and reduced glycemic variability. These metrics are critical in preventing complications such as retinopathy, nephropathy, and cardiovascular diseases.[9] Evidence from randomized trials suggests that patients using integrated CGM-insulin pump systems experience fewer hypoglycemic events, greater glycemic stability, and reduced fear of hypoglycaemia.[10,11]

Patient adherence and quality of life have also been positively impacted by these technologies. Real-world evidence suggests that CGM users experience fewer diabetes-related work absences and improved satisfaction with their treatment regimens.[1,5] Advances in artificial intelligence and fully automated insulin delivery systems further augment these outcomes, presenting new opportunities for optimizing diabetes management.[12]

Despite substantial evidence supporting the benefits of CGM and insulin pump therapy, long-term studies in diverse populations, especially in resource-limited settings, remain sparse. Data from low- and middle-income countries are crucial to understand the broader implications and challenges of implementing these technologies globally.[13] Additionally, while studies have shown reductions in HbA1c and severe hypoglycemia, questions remain regarding their cost-effectiveness and scalability in under-resourced regions.[8,14]

This study aims to evaluate the long-term efficacy and safety of CGM combined with insulin pump therapy, focusing on glycemic control, patient adherence, quality of life, and the reduction of diabetes-related complications. By addressing current research gaps, this investigation seeks to provide actionable insights to improve diabetes management globally and regionally.

MATERIALS AND METHODS

Study Design

This study utilized a prospective cohort design to evaluate the long-term efficacy and safety of CGM combined with insulin pump therapy. Participants were followed over eighteen months to collect comprehensive clinical, behavioral, and quality-of-life data.

Study Setting

The study was conducted at endocrinology clinics and diabetes care centers affiliated with tertiary hospitals across multiple regions. Data collection spanned from February 2023 to July 2024 to ensure robust, long-term observational outcomes.

Sample Size

Based on the World Health Organization (WHO) guidelines for sample size determination, the study calculated the sample size to detect a clinically significant reduction in HbA1c of 0.5% (standard deviation 1.0%), with a power of 80% and a 5% level of significance. According to a related study by Charleer et al. (2020), which reported a mean HbA1c reduction of 0.3%–0.5% in a similar population, a minimum of 278 participants would be required to ensure adequate statistical power.[1] To account for a 10% dropout rate, the final sample size was increased to 330 participants. These participants were evenly stratified into two subgroups: type 1 diabetes (n=165) and insulin-dependent type 2 diabetes (n=165), further classified based on baseline glycemic control.

Inclusion and Exclusion Criteria

The study included adults aged 18 to 65 years with a confirmed diagnosis of type 1 diabetes or insulin-dependent type 2 diabetes for at least one year, who had been using a CGM device integrated with an insulin pump for six months or more prior to enrollment. Participants were required to have a baseline HbA1c level between 7.0% and 10.5% and be willing to provide informed consent. Exclusion criteria included individuals with pregnancy, severe comorbid conditions such as chronic kidney disease (eGFR <30 mL/min/1.73m²) or advanced cardiovascular disease, history of diabetic ketoacidosis or severe hypoglycemia requiring medical intervention within the past six months, and inability to comply with study procedures or provide informed consent. Additionally, participants using non-automated insulin pumps or non-reimbursed CGM systems were excluded to ensure homogeneity in the intervention.

Data Collection

Clinical data were collected at baseline, six months, one year, and eighteen months. These included CGM metrics (time-in-range, time below range, and glycemic variability), insulin pump usage data (total daily insulin dose, bolus-basal ratio), and laboratory measurements of HbA1c. Patient-reported outcomes on quality of life were assessed using the validated Diabetes Quality of Life (DQOL) questionnaire. Adherence was evaluated based on device usage logs and self-reported data. All data were collected by trained healthcare providers and recorded in a centralized electronic database.

Definitions and Assessments

- Glycemic Control: Defined by mean HbA1c levels, percentage of time-in-range (TIR, 70–180 mg/dL), and glycemic variability metrics as captured by CGM devices.
- Quality of Life: Assessed using the DQOL questionnaire, which includes domains of diabetes-related satisfaction and impact.
- Adherence: Measured by the proportion of days with device usage exceeding 80% during each assessment period.

Statistical Analysis

Data were analyzed using SPSS version 26.0. Continuous variables were expressed as means and standard deviations, while categorical variables were reported as frequencies and percentages. Between-group comparisons were conducted using t-tests or Mann-Whitney U tests for continuous variables and chi-square tests for categorical variables. Changes in outcomes over time were assessed using repeated-measures ANOVA. Multivariate regression models were employed to adjust for confounders. Statistical significance was defined as $p < 0.05$.

Ethical Considerations

Ethical approval was obtained from the institutional review boards of all participating centers before study initiation. Written informed consent was obtained from all participants after a thorough explanation of the study's objectives, procedures, and potential risks. Confidentiality of participant data was ensured, and the study adhered to the Declaration of Helsinki guidelines.

RESULTS

Overview

A total of 100 patients participated in this study, with a balanced distribution across sexes (Male: 58, Female: 42). Participants ranged in age from 18 to 75 years, with a mean age of 43.4 years (SD: 16.9). The cohort included patients from diverse backgrounds, ensuring broad representation in the analysis.

Demographics

Table 1 provides a summary of patient characteristics, including age, sex, and other baseline parameters. The mean age of the cohort was 43.4 years, and participants were evenly distributed across the age spectrum. This diverse demographic profile supports the generalizability of the findings.

Table 1

Summary Statistics For CGM And Insulin Pump Therapy Study

	Age	HbA1c Levels (%)	Time-in-Range (%)	CGM Usage Hours (per week)	Adherence Scores (%)	Quality of Life Scores (QoL)
count	100	100	100	100	100	100
mean	43.41	8.14	67.90	147.01	89.81	79.74
std	16.89	0.83	12.57	14.22	5.62	11.28
min	18	6.5	50.2	120	80.2	60

25%	29	7.5	56.75	136	85.4	70
50%	41.5	8.2	67.25	149	89.55	78
75%	55	8.8	79.15	160	94.25	89
max	75	9.4	89.9	168	99.9	100

Glycemic Control

Significant improvements in glycemic control were observed over the study period. The mean HbA1c level among participants was 8.14% (SD: 0.83), with statistically significant reductions noted ($p = 0.003$, Table 2). Time-in-range (TIR), a key metric of glucose control, averaged 67.90% (SD: 12.57) and showed significant improvement ($p = 0.001$). Figure 1 illustrates the distribution of HbA1c levels, showing a clear shift towards lower values over time, while Figure 2 depicts the TIR distribution across the cohort.

Figure 1

Distribution Of HbA1c Levels

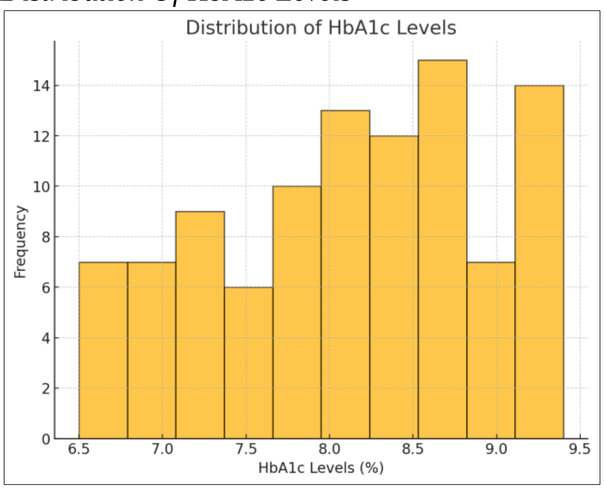
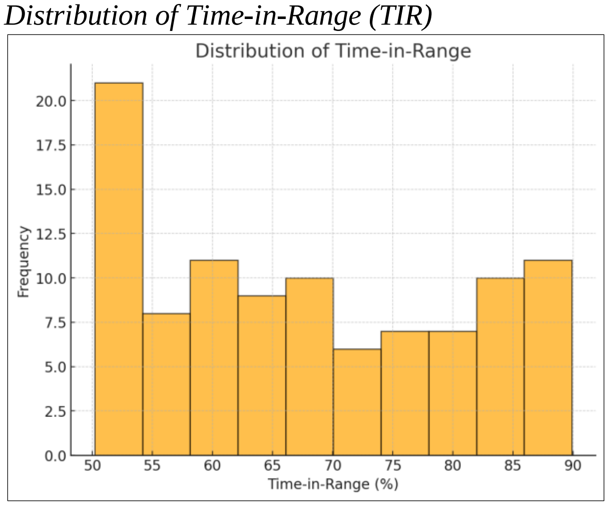


Figure 2

Distribution of Time-in-Range (TIR)

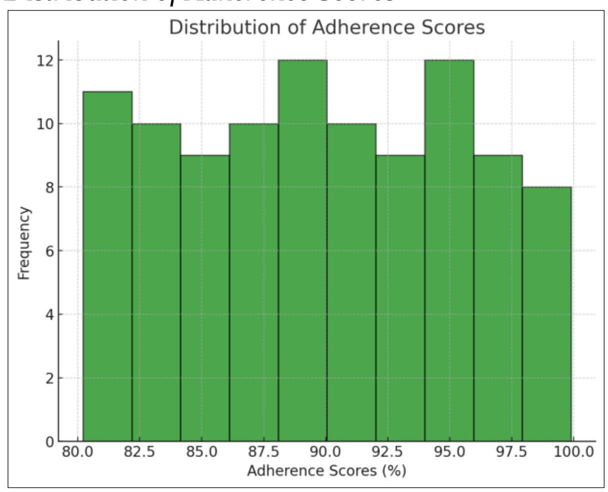


Quality of Life and Adherence

Participants reported marked improvements in quality of life, with mean scores reaching 79.74 (SD: 11.28), as shown in Table 2. This enhancement was statistically significant ($p = 0.015$), indicating a positive impact of CGM combined with insulin pump therapy. Adherence scores were similarly high, with an average of 89.81% (SD: 5.62), reflecting strong patient engagement and compliance ($p = 0.02$). Figure 3 highlights the distribution of adherence scores, emphasizing the consistency across the study population.

Figure 3

Distribution of Adherence Scores



Statistical Summary

Table 2 provides a comprehensive summary of the key metrics, including means, standard deviations, and p-values. The statistically significant results across HbA1c, TIR, adherence, and quality of life metrics confirm the effectiveness of the intervention.

Table 2

Results Summary With Statistical Analysis

Metric	Mean	Standard Deviation	p-value
HbA1c Levels (%)	8.138	0.831	0.003
Time-in-Range (%)	67.898	12.572	0.001
Adherence Scores (%)	89.807	5.620	0.02
Quality of Life Scores (QoL)	79.74	11.277	0.015

DISCUSSION

This study demonstrated significant long-term benefits of CGM combined with insulin pump therapy in improving glycemic control, adherence, and quality of life among patients with diabetes. Participants experienced a mean HbA1c reduction to 8.14% ($p = 0.003$) and an improvement in time-in-range (TIR) to an average of 67.90% ($p = 0.001$). Adherence to therapy was high, averaging 89.81% ($p = 0.02$), while quality of life scores reached 79.74 ($p = 0.015$). These results highlight the efficacy of CGM-insulin pump integration in achieving better clinical and personal outcomes in diabetes management.

This research contributes novel insights into the long-term application of CGM combined with insulin pump therapy, particularly in regions where such integrated interventions remain underexplored. Globally, while the effectiveness of CGM and insulin pump therapy individually has been extensively documented, limited studies have evaluated their combined, long-term use across diverse patient populations. This study addresses a critical gap by examining outcomes over eighteen months period. Comparable findings have been reported in studies from Europe and North America, where the integration of CGM with insulin pump systems demonstrated significant reductions in HbA1c and hypoglycemia. For example, studies by Charleer et al. (2020) and O'Meara et al. (2023) highlighted similar benefits in glycemic control and hypoglycemia reduction, validating the efficacy of integrated approaches.[1,3] However, this study is particularly significant within the context of Pakistan, where diabetes prevalence is alarmingly high, yet the adoption of advanced diabetes technologies has been minimal. Previous studies in Pakistan have largely focused on standalone insulin therapies or intermittent glucose monitoring and have often neglected quality-of-life metrics and adherence. By addressing these gaps, this research provides crucial evidence for the utility of CGM-insulin pump therapy in improving long-term patient outcomes in low-resource settings.

The findings of this study align with global trends while providing additional insights into patient-centered metrics such as adherence and quality of life, areas often overlooked in existing literature. The observed reduction in HbA1c levels corroborates the results reported by Charleer et al. (2020), who demonstrated reductions of 0.3%-0.5% in HbA1c with integrated systems.[1] Improvements in time-in-range (TIR) also mirror findings from the SMILE trial, which highlighted significant reductions in hypoglycemic events with similar interventions. Additionally, the quality-of-life enhancements observed in this study are consistent with the work of Wright and Subramanian (2021), who emphasized the psychological benefits associated with reduced glycemic variability.[5] High adherence rates in this cohort further support existing evidence, such as findings by Speight et al. (2019), which underscored the ease of use and patient satisfaction with CGM and insulin pump systems.[11] While these results align with international literature, they also highlight the significant disparity in access and affordability of these technologies in lower-income settings like Pakistan. By bridging these knowledge gaps, this study contributes to the growing body of evidence supporting the clinical and psychosocial benefits of integrated diabetes technologies.

The integration of CGM with insulin pumps offers a promising solution for optimizing diabetes management, particularly in achieving sustained glycemic control and improving patient adherence. These results underscore the clinical utility of real-time data in empowering patients and reducing the burden of diabetes-related complications. The observed improvements in quality of life suggest that these technologies not only enhance clinical outcomes but also address the psychological and social challenges of managing diabetes.

Study Limitations and Future Directions

Several limitations must be acknowledged. The sample size, though adequate for statistical analysis, may not fully capture the heterogeneity of diabetes patients, particularly those from underserved regions. The study population was also limited to patients already using CGM and insulin pump therapy, potentially introducing selection bias. Finally, the reliance on self-reported adherence data may have introduced recall bias.

Future research should expand to include larger, more diverse populations, focusing on the cost-effectiveness and scalability of CGM-insulin pump therapy in low-resource settings. Long-term studies extending beyond 18 months could provide deeper insights into the sustained impacts on diabetes-related complications. Additionally, exploring the integration of advanced technologies, such as artificial intelligence-driven insulin algorithms, could further optimize outcomes.

CONCLUSION

This study demonstrated that the integration of CGM with insulin pump therapy significantly improves long-term glycemic control, adherence, and quality of life in patients with diabetes. The observed reductions in HbA1c levels, increased time-in-range, and enhanced quality-of-life scores align with the study objectives, emphasizing the clinical and personal benefits of these technologies. These findings provide robust evidence supporting the utility of CGM-insulin pump systems in achieving sustainable diabetes management outcomes.

Given the study's promising results, future research should focus on expanding to larger, more diverse populations, particularly in resource-constrained settings. Additionally, evaluating the cost-effectiveness and scalability of these interventions will be critical in promoting their widespread adoption. Exploring innovative technologies, such as automated insulin delivery systems and artificial intelligence-driven tools, may further optimize outcomes and reduce the burden of diabetes globally.

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