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The Relationship Between the Frequency of Self-Monitoring of Blood Sugar and Hemoglobin A1c (HbA1c) in Children with Type 1 Diabetes Mellitus

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ABSTRACT

Type 1 Diabetes Mellitus (T1DM) is an autoimmune disorder characterized by pancreatic β-cell destruction and chronic hyperglycemia. Self-Monitoring of Blood Glucose (SMBG) is essential for daily glycemic regulation, yet its impact on long-term outcomes such as Hemoglobin A1c (HbA1c) remains unclear in pediatric populations. This cross-sectional study involved 38 children with T1DM recruited through consecutive sampling from IKADAR East Java to examine the association between SMBG frequency and HbA1c levels. SMBG frequency (times/day) and the most recent HbA1c value (%) were obtained through structured interviews and medical records. Statistical analyses (Shapiro–Wilk, Spearman correlation, Chi-square, and Mann–Whitney U tests) showed a weak, non-significant negative correlation between SMBG frequency and HbA1c ($r_s = -0.165$; $p = 0.323$), with no significant differences across SMBG categories. These findings indicate that SMBG frequency alone is not associated with improved HbA1c in children with T1DM, suggesting that glycemic control may depend more on insulin adherence, caregiver support, and access to continuous glucose monitoring technologies.

Keywords: type 1 diabetes mellitus; HbA1c; SMBG; blood glucose monitoring; children

INTRODUCTION

Type 1 Diabetes Mellitus (T1DM) is a chronic autoimmune disease characterized by the destruction of pancreatic β-cells, leading to absolute insulin deficiency in children [1]. Self-Monitoring of Blood Glucose (SMBG) remains a key component of diabetes management [2]. Globally, the prevalence of T1DM continues to increase, with an estimated 8.75 million cases worldwide, of which 1.52 million occur in children and adolescents under 20 years old. Low- and middle-income countries account for one-fifth of all cases, and Southeast Asia ranks fourth with approximately 900,000 cases [3]. Mortality remains substantial, with 182,000 deaths recorded in 2022 and 42,000 occurring in Southeast Asia [4]. In Indonesia, the Indonesian Pediatric Society reported 1,249 children diagnosed between 2017 and 2019, with diabetic ketoacidosis present in 71% of cases, an increase from 63% in 2015–2016, reflecting persistent delays in diagnosis and suboptimal glycemic control [5]. These delays increase the risk of severe acute complications such as ketoacidosis and chronic complications, including microvascular disease, neuropathy, and neurocognitive impairment [6].

Hemoglobin A1c (HbA1c) is the primary biomarker used to assess long-term glycemic control and is routinely monitored to ensure that average glucose levels remain within therapeutic targets in children with T1DM [7]. However, glucose monitoring practices vary widely between patients, especially in low-resource settings where access to continuous glucose monitoring (CGM) is limited. In contrast to high-income countries, where CGM is widely accessible, developing countries face barriers including high device costs, limited insurance coverage, and insufficient patient education [8,9]. Insulin availability also remains a challenge in health systems with restricted financial protection [10]. In Indonesia, the recommended SMBG frequency is 4–6 checks per day, yet only 20% of patients report checking their glucose at least three times daily, partly due to the out-of-pocket cost of glucometers and test strips, which are not covered by the national insurance system [5,11]. Evidence regarding the relationship between SMBG frequency and HbA1c control in pediatric T1DM remains inconsistent, underscoring the need for further research, particularly in low- and middle-income contexts.

This study was conducted to determine whether an association exists between the frequency of SMBG and HbA1c levels in children with T1DM. The study seeks to describe SMBG practices, assess HbA1c outcomes, and evaluate whether monitoring frequency contributes significantly to glycemic control. The findings of this research are expected to contribute to the scientific understanding of glucose monitoring behavior in pediatric diabetes management, enhance awareness of glycemic control strategies, and support improved quality of life for patients. Practically, this research may assist healthcare providers, patients, and families in reducing the risk of acute and chronic complications, strengthening treatment adherence, and emphasizing the importance of regular glucose and HbA1c monitoring. The results also have the potential to inform health policy development regarding appropriate SMBG frequency to optimize glycemic outcomes among children living with T1DM.

LITERATURE REVIEW

Type 1 Diabetes Mellitus (TIDM)

Type 1 diabetes mellitus (T1DM) is an autoimmune T-cell–mediated disease characterized by chronic destruction of pancreatic β-cells, leading to absolute insulin deficiency [12]. Genetic susceptibility and early-life environmental exposures significantly contribute to disease onset [13]. As a result of progressive β-cell loss, lifelong insulin therapy via multiple daily injections, insulin pumps, or automated insulin delivery systems is required to prevent life-threatening complications such as diabetic ketoacidosis. Continuous glucose monitoring (CGM) is now recommended to optimize glycemic control [1].

T1DM is a multifactorial and polygenic disorder with substantial genetic heterogeneity. Heritability studies show monozygotic twin concordance of 30–70% and a sibling risk 10-fold higher than the general population [14]. Both HLA and non-HLA loci contribute to disease susceptibility, and genetic risk scores (GRS) help predict islet autoimmunity and progression to clinical diabetes [15]. Recent investigations emphasize the role of genes such as INS, PTPN22, TYK2, CD226, IFIH1, and CTLA4. Advances in genome-wide association studies, rare SNP analyses, and epigenetic profiling have improved prognostic modelling, though limited knowledge of rare variants remains a challenge [16].

Serological markers particularly autoantibodies to insulin (IAA), GAD65 (GADA), IA-2, ZnT8, and ICA serve as predictive biomarkers, with earlier IAA seroconversion associated with faster progression [13,15]. Age at seroconversion also reflects disease heterogeneity, influencing immunological patterns and β-cell decline rates. Emerging evidence supports the concept of T1DM "endotypes," which differ in genetic profiles, immune mechanisms, and clinical progression, potentially guiding future precision therapies [17,18].

Environmental and lifestyle factors including vitamin D deficiency, early cow's milk exposure, gluten intake, and colder climates have also been linked to increased T1DM risk [19]. Pathophysiologically, T1DM involves autoimmune insulitis triggered by interactions between antigen-presenting cells and autoreactive T-cells, resulting in inflammatory cytokine release and β-cell apoptosis [20,21]. Clinical symptoms typically appear only after 80–90% of β-cell mass is destroyed.

Biomarker research continues to expand, identifying differential microRNA (miRNA) expression profiles and circulating proteins involved in complement pathways, lipid metabolism, and immune responses, which may serve as novel diagnostic markers [22,23].

Globally, 8.75 million people were living with T1DM in 2022, with rising incidence in both children and adults. Alarmingly, many young individuals in low-income settings die from unrecognized diabetic ketoacidosis due to delayed diagnosis [4]. The average global age of individuals with T1DM is now 40 years, reflecting improved survival and healthcare access.

Management of T1DM requires immediate initiation of insulin therapy at diagnosis. Treatment goals include optimizing glycemic control, preventing microvascular and metabolic complications, and improving quality of life. Comprehensive care involves insulin therapy, lifestyle modification, monitoring of blood pressure and lipids, and prevention of insulin-resistance–related metabolic risk factors [24]. Personalized treatment plans and multidisciplinary care teams are essential to accommodate the significant clinical heterogeneity of T1DM.

Self-Monitoring of Blood Glucose (SMBG)

Self-Monitoring of Blood Glucose (SMBG) is a fundamental component of diabetes management, originating from the introduction of the first home-use glucometers in the 1970s and continuing to evolve into the standard of care for Type 1 Diabetes Mellitus (T1DM) [6]. Over time, SMBG technology has advanced substantially in terms of device size, speed, usability, and accuracy, with modern systems requiring only minimal capillary blood and providing results within seconds, although some devices still do not fully meet international accuracy standards [2,6]. Contemporary SMBG devices increasingly incorporate features such as connectivity to other devices, digital logs, and integrated diabetes-management tools, further supporting users in tracking glucose fluctuations and facilitating more precise insulin-dosing decisions [2]. Regular SMBG plays a crucial role in guiding rapid-acting insulin adjustment, planning around physical activity, managing hypoglycemia, and assessing postprandial glycemic responses, often requiring 6–10 daily measurements to identify patterns, correct real-time hyperglycemia, adjust basal insulin, and refine

carbohydrate-to-insulin ratios [5]. Despite these technological advancements, challenges such as device accuracy, cost barriers, and limited patient education continue to impede optimal SMBG utilization in several countries, including China, India, and Brazil; nevertheless, increased ease of use, reduced finger-stick pain, and enhanced patient confidence have encouraged more frequent monitoring among users [25].

HbA1c

Hemoglobin A1c (HbA1c) is the predominant biomarker for assessing long-term glycemic control in individuals with diabetes and is formed through the non-enzymatic covalent attachment of glucose to the N-terminal valine of the β-chain of adult hemoglobin (HbA), in which approximately 6% is glycated, with HbA1c constituting the major fraction [26]. Because erythrocytes have an average lifespan of 120 days, HbA1c reflects mean blood glucose levels over the prior 8–12 weeks, with roughly 50% of its value representing glycemia in the last 30 days, 40% from the preceding 31–90 days, and 10% from the preceding 91–120 days [26]. Since 2010, the American Diabetes Association (ADA) has recommended HbA1c as a diagnostic and monitoring standard, defining values ≥6.5% as diabetes, 5.7–6.4% as prediabetes, and <5.7% as normal, with testing advised twice yearly for stable, well-controlled patients and quarterly for those undergoing therapy changes or exhibiting poor control [7,27]. HbA1c testing offers advantages such as not requiring fasting and having stable sample characteristics, but its accuracy can be affected by numerous clinical conditions, including altered erythrocyte turnover, hemoglobinopathies, nutritional deficiencies, chronic kidney or liver disease, transfusions, pregnancy, ethnicity-related variations in glycation, and other physiological or pharmacological factors that may lead to falsely low or falsely elevated results [7,26]. For diagnostic purposes, HbA1c results should not be used in isolation in asymptomatic individuals; rather, confirmation with repeat HbA1c or plasma glucose testing via fasting plasma glucose, random glucose, or oral glucose tolerance test is required, and diagnosis should rely on standardized laboratory methods rather than point-of-care devices to ensure accuracy [28].

Relationship Between SMBG Frequency and HbA1c

Hemoglobin A1c (HbA1c) reflects average blood glucose over approximately three months and is recommended by the American Diabetes Association (ADA) as a primary indicator of long-term glycemic control, with a therapeutic target of <7% to reduce diabetes-related complications; however, HbA1c testing can only be performed at three-month intervals and does not capture daily glycemic fluctuations, making it less reliable in patients who recently initiated insulin or hypoglycemic therapy (<3 months) or in individuals with conditions affecting erythrocyte turnover, such as hemoglobin variants, thalassemia, hemolysis, recent blood transfusion, or pregnancy [29]. In such cases, HbA1c may not accurately reflect glycemia, and real-time glucose monitoring tools become essential. Continuous Glucose Monitoring (CGM) offers comprehensive glycemic profiling but is limited by high cost, whereas Self-Monitoring of Blood Glucose (SMBG) remains a practical and widely accessible method that enables patients to adjust treatment regimens promptly and evaluate immediate effects of lifestyle or therapeutic changes [29].

CONCEPTUAL FRAMEWORK

Type 1 diabetes mellitus (T1DM) arises from autoimmune destruction of pancreatic β-cells driven by both genetic predisposition and environmental triggers, ultimately resulting in absolute insulin deficiency and the lifelong need for exogenous insulin and routine blood glucose surveillance. Effective management of T1DM depends heavily on patient adherence, which encompasses lifestyle modification, specifically diet regulation and physical activity alongside insulin therapy, structured diabetes education, and self-monitoring of blood glucose (SMBG). Within SMBG, both the frequency of monitoring and the glucose values obtained play a decisive role in guiding daily glycemic management. Adherence to these components directly influences the ability of patients to track and interpret their glucose levels accurately. Adequate and consistent monitoring supports good glycemic control, while poor adherence or insufficient monitoring predisposes patients to suboptimal glycemic regulation. These differences in daily control are ultimately reflected in hemoglobin A1c (HbA1c) levels, which serve as the primary long-term indicator of glycemic management in individuals with T1DM. Based on this conceptual relationship, the study hypothesizes that there is a significant association between the frequency of SMBG and HbA1c levels among children with type 1 diabetes mellitus.

RESEARCH METHODS

This study employed an analytical observational design using a cross-sectional approach based on primary data obtained through structured interviews with caregivers of children diagnosed with type 1 diabetes mellitus (T1DM). The study population consisted of pediatric T1DM patients who were members of a regional Diabetes Community, and the sample included children aged 2–18 years who met the inclusion criteria and did not fulfill the exclusion criteria during the data collection period in November 2024. The minimum required sample size was calculated using the correlation coefficient estimation formula (Statistic and Sample Size Pro, 2020), applying an alpha of 0.05, a beta of 0.20, and an anticipated correlation coefficient of r = 0.6, resulting in a required sample of at least 20 participants. A consecutive sampling technique was used to recruit eligible participants, excluding children with acute complications requiring intensive care or those with hematologic conditions such as anemia, thalassemia, or hemolysis, which could interfere with HbA1c accuracy.

The independent variable was the frequency of self-monitoring blood glucose (SMBG), while the dependent variable was the Hemoglobin A1c (HbA1c) level, with all variables operationally defined according to established diagnostic guidelines [7,11,30–34]. Data were collected using an interview guide covering demographic information, recent SMBG frequency over the previous seven days, and the most recent HbA1c results within the past four months. Research activities were conducted during the Diabetes Community Gathering in Surabaya between July 2024 and July 2025. Data processing included editing, coding, entry, and cleaning using Microsoft Excel to ensure accuracy and completeness. Statistical analysis assessed the association between SMBG frequency and HbA1c levels using either Pearson's correlation for normally distributed data or Spearman's rank correlation for non-normal distributions, with interpretation of correlation strength based on Sarwono (2006). Ethical principles of confidentiality, anonymity, and beneficence were strictly upheld throughout the study.

RESULT AND ANALYSIS

This study involved 38 children with type 1 diabetes mellitus (T1DM), most of whom were female (76.3%) and within the 10–17-year age range, a developmental period marked by hormonal fluctuations, insulin resistance, and increasing behavioral independence that complicate diabetes self-management. The median disease duration was 3.6 years, reflecting mid-term management experience. However, the median HbA1c level of 9.65% (range 7.5–15.9%) indicates suboptimal glycemic control, falling short of the <7.5% target recommended by the American Diabetes Association for children and adolescents. International comparisons show considerably better glycemic outcomes in Japan and Western Europe, where HbA1c averages 7.0–7.6% driven by broader access to Continuous Glucose Monitoring (CGM), insulin pump therapy, and structured diabetes education [35–37]. Female adolescents often demonstrate higher HbA1c values, consistent with international registry findings associating pubertal hormonal changes with increased insulin resistance. These disparities highlight the influence of socioeconomic factors, healthcare access, and family involvement on glycemic outcomes in Indonesia.

The median self-monitoring blood glucose (SMBG) frequency was 5 times per day, with 65.8% of participants performing SMBG ≥4 times daily, aligning with clinical recommendations [11]. The wide variability observed suggests differing levels of adherence, influenced by age, parental support, resource availability, and psychosocial factors such as diabetes distress among adolescents [38]. Local evidence similarly shows that higher SMBG frequency correlates with better treatment adherence only when accompanied by appropriate follow-up actions [11]. Thus, while monitoring remains essential, its effectiveness is shaped by behavioral and contextual determinants.

Despite relatively frequent SMBG, most respondents exhibited poor glycemic control (68.4%), with very few achieving optimal levels. When compared to international benchmarks, these findings indicate that SMBG alone is insufficient without comprehensive therapeutic guidance, technological support, and consistent family or caregiver involvement. CGM adoption, shown to significantly reduce HbA1c and improve time-in-range in multiple studies, appears to offer superior benefits relative to SMBG alone [35,39,40].

The study found no statistically significant association between SMBG frequency and HbA1c ($r_s = -0.165$, $p = 0.323$). Although the correlation direction suggests that more frequent monitoring tends to accompany lower HbA1c, the relationship is weak and clinically negligible. This aligns with evidence indicating that SMBG yields meaningful improvements only when results are interpreted and followed by appropriate insulin adjustments, dietary regulation, and timely responses to glycemic fluctuations. Contributing factors that may obscure this relationship include variability in treatment adherence, socioeconomic barriers limiting access to supplies, family involvement, and differences in disease duration. Research shows that newly diagnosed patients often display higher HbA1c values due to adaptation challenges, whereas adolescents with longer disease duration may experience treatment fatigue, both of which influence monitoring behavior and glycemic outcomes [41,42]. These confounders help explain the non-significant association observed.

Overall, the findings highlight that increasing SMBG frequency in isolation does not ensure better glycemic control. Effective management requires structured diabetes education, strong family support, timely clinical supervision, and, where feasible, technological advancements such as CGM. Policy-level support, including subsidies for monitoring tools, may also be critical to improving glycemic outcomes in Indonesian children with T1DM.

CONCLUSIONS

The study reveals several key insights regarding blood glucose monitoring practices and glycemic control among children with type 1 diabetes. First, the descriptive analysis indicates that the median frequency of self-monitoring blood glucose (SMBG) was five times per day, with most respondents performing six daily checks. Despite frequent monitoring, the median HbA1c level remained elevated at 9.65%, suggesting that the majority of patients had not yet achieved optimal glycemic targets and continued to experience chronic hyperglycemia.

Furthermore, the analysis found no statistically significant association between SMBG frequency and recent HbA1c levels. Although the correlation trend indicated that more frequent monitoring tended to be associated with lower HbA1c values, the relationship was weak and non-significant across all statistical tests, including correlation analysis, Chi-square testing, median-based group comparisons, and the Mann-Whitney test.

Several recommendations arise from these findings. Future studies are encouraged to incorporate more advanced glucose monitoring technologies, such as Continuous Glucose Monitoring (CGM), and to use prospective or longitudinal designs to better examine causal pathways. Additionally, controlling for major confounding factors such as insulin dosage, dietary patterns, and physical activity is essential for producing more accurate and generalizable results.

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