International Journal of Research and Review
[Indexed, Peer-Reviewed Journal]
Volume 13; Issue: 2; February 2026
Website: www.ijrrjournal.com
Research Paper *E-ISSN: 2349-9788; P-ISSN: 2454-2237*

Relationship between Glycemic Control and Blood Pressure in Pediatric Patients with Type 1 Diabetes Mellitus at Dr. M. Djamil Hospital Padang

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DOI: https://doi.org/10.52403/ijrr.20260206

ABSTRACT

Background: The prevalence of type 1 diabetes mellitus (T1DM) in children is increasing globally, with hypertension as a common comorbidity. Research examining the relationship between glycemic control and blood pressure in pediatric T1DM remains limited.
Methods: A cross-sectional study was conducted at Dr. M. Djamil Hospital Padang from December 2024 to November 2025. Sixty T1DM patients aged 6 months to 18 years were included through consecutive sampling. Glycemic control was assessed using HbA1c levels, and blood pressure was measured using a digital sphygmomanometer. Data were analyzed using Chi-Square test with significance level $p<0.05$.
Results: The majority of respondents (78.3%) had poor glycemic control (HbA1c >7.0%), while 21.7% achieved target control. Blood pressure distribution showed 55.0% normotensive, 11.7% elevated blood pressure, 20.0% stage 1 hypertension, and 13.3% stage 2 hypertension. Chi-Square analysis revealed no significant relationship between glycemic control and blood pressure ($p=0.190$).
Conclusion: No significant association was found between glycemic control and blood pressure in pediatric T1DM patients. However, the high prevalence of both poor glycemic control and hypertension emphasizes the need for education and blood pressure screening.

Keywords: Type 1 diabetes mellitus, glycemic control, HbA1c, blood pressure, hypertension, pediatric

INTRODUCTION

Diabetes mellitus represents a complex metabolic disorder characterized by chronic hyperglycemia resulting from defects in insulin secretion, insulin action, or both. [1] The condition manifests when inadequate insulin secretion or diminished tissue responsiveness to insulin leads to impaired insulin action on target tissues, subsequently causing abnormalities in carbohydrate, fat, and protein metabolism. The etiology of diabetes mellitus can be classified into two primary categories: Type 1 Diabetes Mellitus (T1DM), which results from deficiency in insulin secretion, and Type 2 Diabetes Mellitus (T2DM), which arises from insulin resistance. [1]

The prevalence of diabetes mellitus among children and adolescents continues to increase globally, establishing it as a significant public health concern. According to data from the International Diabetes

Federation in 2021, approximately 1.2 million children and adolescents aged 0-19 years worldwide live with T1DM, with a global incidence of 15 per 100,000 population per year. [2] A recent systematic review from 2021 reported a significant global increase in the incidence of T2DM among children and adolescents, with variations across countries and ethnicities, estimating a global rate of 0.18 per 1000 children and adolescents. [3]

In Indonesia, data from the Indonesian Pediatric Society in 2018 recorded 1,220 children with T1DM.[4] Notably, in 2017, 71% of children with T1DM were first diagnosed with diabetic ketoacidosis, an increase from 63% in both 2016 and 2015.[4]

The primary objectives of diabetes mellitus therapy include achieving optimal glycemic control, maintaining normal growth and development, preventing complications, and providing psychological support to the child and family. [5] Hypertension constitutes a frequent comorbidity in patients with diabetes mellitus, including children. A prospective multicenter study conducted by SEARCH for Diabetes in Youth found that 14.8% of children with T1DM developed hypertension within an average of 7.1 years after diagnosis, particularly among those who had prehypertension initially and experienced central obesity. [6]

Research investigating the relationship between glycemic control and blood pressure in children with T1DM remains limited. This study aims to analyze the relationship between glycemic control and blood pressure in pediatric T1DM patients at DR. M. Djamil Hospital Padang, with the objective of understanding whether maintaining optimal glycemic control can help prevent hypertension development in this vulnerable population.

MATERIALS AND METHODS

Study Design

This research employed a cross-sectional study design to investigate the relationship between the independent variable, glycemic control, and the dependent variable, blood pressure, in pediatric patients with Type 1 Diabetes Mellitus.

Study Location and Duration

The research was conducted at the Pediatric Outpatient Clinic of DR. M. Djamil Hospital Padang and the Clinical Laboratory of DR. M. Djamil Hospital Padang. The study period extended from December 2024 to November 2025.

Study Population and Sample

The study population comprised all pediatric patients with Type 1 Diabetes Mellitus receiving care at the pediatric clinic, aged 6 months to 18 years at DR. M. Djamil Hospital Padang. Sample selection was performed through consecutive sampling methodology.

Sample Size Calculation

The minimum sample size for this study was determined using the standard formula for estimating proportions in a population. Based on previous research by Steven and colleagues in 2023, which reported a hypertension prevalence of 19.4% among children with type 1 diabetes mellitus, [28] we calculated the required sample size using a 95% confidence interval (Z-value of 1.96) and a precision level of 10%. The calculation yielded a minimum sample size of 60 participants.

Inclusion and Exclusion Criteria

Inclusion criteria required participants to be willing to participate in the study and sign informed consent. Exclusion criteria eliminated patients already known to have hypertension before T1DM diagnosis.

Research Variables

The research variables included glycemic control as the independent variable and blood pressure as the dependent variable.

Operational Definitions

Glycemic Control was defined as the optimal serum glucose concentration in patients with diabetes mellitus. Measurement involved

collecting 3 ml of venous blood aseptically by laboratory personnel, storing it in a vacutainer at 2-8°C, and measuring using the High-Performance Liquid Chromatography method with Afinion and cobas integra instruments. Results were classified as controlled if HbA1c ≤7.0% and uncontrolled if HbA1c >7.0%, [8, 9] using an ordinal scale.

Blood Pressure was defined as the pressure generated by blood against arterial vessel walls, with normal values in children varying based on age, sex, and height.[10,11] Results were classified according to American Academy of Pediatrics 2017 guidelines.[11,12] For children aged 1 to less than 13 years: normal blood pressure (systolic and diastolic blood pressure less than 90th percentile for age, sex, and height), elevated blood pressure (systolic or diastolic blood pressure between 90th to less than 95th percentile), stage 1 hypertension (systolic or diastolic blood pressure at or above 95th percentile to less than 95th percentile plus 12 mmHg), and stage 2 hypertension (systolic or diastolic blood pressure at or above 95th percentile plus 12 mmHg). For children aged 13 years and older: normal blood pressure (systolic less than 120 and diastolic less than 80 mmHg), elevated blood pressure (systolic 120-129 and diastolic less than 80 mmHg), stage 1 hypertension (systolic 130-139 or diastolic 80-89 mmHg), and stage 2 hypertension (systolic at or above 140 or diastolic at or above 90 mmHg). Results were measured on an ordinal scale.

Research Procedures

All T1DM patients presenting to the Pediatric Endocrinology Clinic at DR. M. Djamil Hospital Padang who met the inclusion criteria were selected as research samples. Informed consent was obtained from parents or guardians agreeing to participate in the research. Parents and children were educated regarding blood pressure and HbA1c examination procedures. Basic data were recorded, including name, age, sex, age at diagnosis, duration of diabetes, and family history of hypertension.

Blood pressure examination was performed by the researcher following standardized protocols. [11, 13] Research participants were asked to sit upright in a prepared chair with both feet touching the floor. The room was prepared in a quiet and cool condition. Blood pressure measurement was conducted 30 minutes after the participant had been seated and resting. An appropriately sized cuff was placed on the bent right arm at 90° parallel to the heart. The cuff length should cover 80-100% of the upper arm circumference and the cuff width approximately 40% of the upper arm circumference. The cuff was positioned on the upper arm, with the lower border 2-3 cm above the cubital fossa and the center of the bladder over the brachial artery. Measurements were performed at least three times with 1–2-minute intervals, with the average value taken as the final reading.

Blood samples were collected from research subjects, obtaining 3 ml of venous blood aseptically by trained personnel and stored in a vacutainer at 2-8°C. If patients had previous HbA1c blood test results from DR. M. Djamil Hospital Laboratory (within less than 3 months), these results could be used in this research and blood examination did not need to be repeated. HbA1c examination was performed at the DR. M. Djamil Hospital Padang laboratory.

Data Processing and Analysis

Data analysis was performed in two stages: univariate analysis to examine the distribution of dependent and independent variables in the research, with categorical variables presented as frequency and percentage and numerical variables presented as mean and standard deviation, and bivariate analysis to determine the relationship between the independent variable (glycemic control) and dependent variable (blood pressure) in pediatric T1DM patients using Chi-Square test. Results were considered statistically significant if p-value was less than 0.05. All data were analyzed using computerized programs.

Ethical Considerations

This research was conducted in full compliance with ethical principles governing human subject research and received formal ethical clearance from the Research Ethics Committee of the Faculty of Medicine at Andalas University in conjunction with DR. M. Djamil Hospital Padang.

RESULTS

Respondent Characteristics

Table 1. Respondent Characteristics

Characteristics (n=60)	(*n*=60)	*f* (%)
Age (years))		
0-4 years	3	(5%)
5-9 years	8	(13.3%)
10-14 years	17	(28,3%)
15-<19 years	32	(53.3%)
Gender		
Male	26	(43.3%)
Female	34	(56.7%)
Age at diagnosis (years)		
0-4 years	9	(15,0%)
5-9 years	14	(23,3%)
10-14 years	31	(51.7%)
15-<19 years	6	(10,0%)
Duration of T1DM (years)		
< 5 years	43	(71.7%)
≥ 5 years	17	(28,3%)
Nutritional status		
Undernutrition	9	(15.0%)
Normal nutrition	43	(71.7%)
Overnutrition	7	(11.7%)
Obesity	1	(1.7%)
Parental history of hypertension		
Present	7	(11.7%)
Absent	53	(88.3%)
Pubertal status		
Prepubertal	16	(26.7%)
Pubertal	44	(73.3%)

This cross-sectional study examined pediatric patients with T1DM receiving care at the Pediatric Endocrinology Clinic of DR. M. Djamil Hospital Padang from December 2024 to November 2025. Respondent selection was performed through consecutive sampling, with 60 patients included in the study (see Table 1).

The age distribution of respondents showed the highest proportion in the 15 to less than 19 years group (53.3%), followed by 10-14 years (28.3%), 5-9 years (13.3%), and 0-3 years (5.0%). The mean age of 13.5±4.8 years indicated variation from preschool children to late adolescents. Gender distribution in this study showed a slightly higher proportion of females (56.7%) compared to males (43.3%), with a ratio of 1.3:1. Age at diagnosis distribution showed more patients were diagnosed in the 10–14-year age range (51.7%), followed by 5-9 years (23.3%), 0-4 years (15.0%), and 15-19 years (10.0%).

Distribution of T1DM duration showed 71.7% of respondents had the condition for less than 5 years, while 28.3% had suffered from diabetes for 5 years or more. Nutritional status evaluation showed that most respondents (71.7%) had good nutritional status, followed by 15.0% with undernutrition, 11.7% with overnutrition, and 1.7% with obesity. History of parental hypertension showed that the majority of respondents (88.3%) had no history of

hypertension in either parent, while 11.7% had a parental history of hypertension. Pubertal status in respondents revealed the highest proportion (73.3%) had entered puberty (Tanner 2-5), while 26.7% of respondents were in the prepubertal phase (Tanner 1).

Glycemic Control of Respondents

Glycemic control targets were established based on recommendations from the American Diabetes Association and International Society for Pediatric and Adolescent Diabetes in their 2022 consensus with an HbA1c target of less than 7%.[8,9,14] The results showed that the majority of respondents (78.3%) had uncontrolled glycemic control (HbA1c greater than 7.0%), while 21.7% of respondents achieved good target glycemic control (HbA1c less than or equal to 7.0%).

Table 2. Glycemic Control of Respondents Based on HbA1c Levels

Glycemic Control (n)	(n)	f (%)
Controlled (HbA1c ≤ 7.0%)	13	21,7
Uncontrolled (HbA1c > 7.0%)	47	78,3
Total	60	100,0

Blood Pressure of Respondents

Table 3. Blood Pressure Distribution of Respondents

Blood Pressure (n)	(n)	f (%)
Normal	33	55,0
Elevated BP	7	11,7
Stage 1 Hypertension	12	20,0
Stage 2 Hypertension	8	13,3
Total	60	100,0

Blood pressure measurement was performed using a Riester digital sphygmomanometer on the right upper arm of respondents with cuff sizes adjusted to patient age. Measurements were conducted three times with a minimum interval of 1-2 minutes between measurements. The final value was taken from the average of measurements. The average results were classified according to American Academy of Pediatrics 2017 guidelines as the latest standard in determining blood pressure in children. [11, 12] The results showed that the majority of respondents' blood pressure (55.0%) was within normal limits, followed by 20.0% with stage 1 hypertension, 13.3% with stage 2 hypertension, and 11.7% with elevated blood pressure.

Relationship between Glycemic Control and Blood Pressure

This study aimed to assess the relationship between glycemic control and blood pressure in children with T1DM. The distribution of glycemic control based on blood pressure status showed that in the group with normal blood pressure, the majority of respondents (81.2%) had uncontrolled glycemic control. In the group with elevated blood pressure, all respondents (100%) did not achieve glycemic targets. The highest proportion of patients with good glycemic control (41.7%) was found in the stage 1 hypertension group.

Most respondents showed uncontrolled glycemic control results at 78.3% (47 patients), while the remainder achieved normal glycemic control at 21.7% (13 patients). The p-value of 0.190 indicated that there was no relationship between glycemic control and blood pressure in pediatric T1DM patients.

Table 4. Relationship between Glycemic Control and Blood Pressure (n=60)

		Glycemic Control					
Blood Pressure Status		**Controlled**		**Uncontrolled**		**Total**	***p-value***
		(n)	***f* (%)**	***(n)***	***f* (%)**	***(n) f* (%)**	**0,190**
	Normal	6	(18,2%)	27	(81,8%)	33 (100%)	
	Elevated BP	0	(0,0%)	7	(100,0%)	7 (100%)	
	Stage 1 Hypertension	5	(41,7%)	7	(58,3%)	12 (100%)	
	Stage 2 Hypertension	2	(25,0%)	6	(75,0%)	8 (100%)	

DISCUSSION

Respondent Characteristics

The predominant age group in this research comprised adolescents aged 15 to less than 19 years (53.3%), followed by 10-14 years (28.3%), 5-9 years (13.3%), and 0-3 years (5.0%). The majority of respondents being adolescent-aged requires special attention because during adolescence, complex physiological changes occur, including pubertal development that affects insulin resistance and glycemic control. The pubertal period increases insulin resistance by up to 30% compared to prepubertal and adult periods, resulting in higher insulin requirements and worsening glycemic control. [15]

Gender distribution showed a slightly higher proportion of females (56.7%) compared to males (43.3%) with a ratio of 1.3:1. Research by the Australasian Diabetes Data Network in 2023 on 6,338 pediatric T1DM patients showed a distribution of 52.6% males and 47.4% females. [16]

Age at diagnosis distribution showed that most patients (51.7%) were diagnosed in the 10–14-year age range. The basis for this age grouping at diagnosis was based on the SEARCH study which grouped data on children with T1DM into age groups 0-4 years, 5-9 years, 10-14 years, and 15-19 years to analyze glycemic control in adolescents with diabetes.[17] This finding aligns with research by Gregory and colleagues in 2022, which showed the peak incidence of T1DM at ages 10-14 years (5-50 per 100,000 children per year in the United Kingdom).[18]

The distribution of T1DM duration in respondents showed 71.7% had a duration of less than 5 years, while 28.3% had suffered from diabetes for 5 years or more. The relatively short duration in most respondents has significant clinical implications, considering that the risk of microvascular complications (retinopathy, nephropathy, neuropathy) and macrovascular complications increase progressively with disease duration. [19]

Diabetes duration represents an important prognostic factor for the development of vascular complications, including hypertension. Chronic hyperglycemia exposure causes progressive vascular endothelial damage through several mechanisms, including increased oxidative stress, formation of advanced glycation end products, activation of the polyol pathway, and activation of protein kinase C.[20] Microvascular complications, including blood pressure changes, most frequently occur after puberty onset and after a diabetes duration of 5-10 years. Therefore, the American Diabetes Association recommends annual screening for albuminuria with random spot urine samples for albumin-creatinine ratio should be considered at puberty or age greater than 10 years, whichever comes first, after the child has had diabetes for 5 years.[21] The International Society for Pediatric and Adolescent Diabetes in 2018 also recommends albuminuria screening starting from age 11 years with a diabetes duration of 2-5 years.[22] This research grouped T1DM duration with a 5-year threshold because a diabetes duration of 5 years or more accompanied by pubertal status represents the highest risk for microvascular complications.[22]

Nutritional status evaluation showed that most respondents (71.7%) had good nutritional status. The Pittsburgh Epidemiology of Diabetes Complications study showed an increase in the prevalence of overnutrition from 29% to 42% and obesity increased seven-fold from 3% to 23% during 18 years of follow-up. The main contributing factor is the significant anabolic effect of insulin in T1DM patients. The intensive insulin therapy required for glycemic control causes increased fat and protein synthesis and increases energy storage in the form of body fat. [23]

Analysis of parental hypertension history showed that the majority of respondents (88.3%) had no history of parental hypertension, while 11.7% had a parental history. Children with diabetes who have a history of parental hypertension face dual risk factors from both genetic and metabolic perspectives, which together increase the risk

of hypertension and early cardiovascular complications. [24]

Pubertal status in respondents showed 73.3% had entered puberty at Tanner stages 2-5, while 26.7% had not experienced puberty or were prepubertal (Tanner 1). Literature shows that puberty constitutes a critical period with significant hormonal changes affecting glycemic control and blood pressure independently.[25] A study by Szyszkowicz and colleagues in 2023 reported peak hypertension prevalence at age 14 years (7.89%), coinciding with the late pubertal period.[26] During puberty, insulin effectiveness decreases by 30-50%, especially at Tanner stages 3-5, which may explain the high proportion of poor glycemic control in this research sample.[27] Adolescents with T1DM experience a 33-42% greater decrease in insulin sensitivity compared to non-diabetic children, mainly due to increased growth hormone and insulin-like growth factor-1 levels during puberty. Higher growth hormone levels in T1DM disrupt insulin signaling pathways and increase insulin resistance, thus exacerbating ketogenesis and the risk of glycemic decompensation and diabetic ketoacidosis. [18]

Glycemic Control of Respondents

Analysis of glycemic control based on HbA1c levels in this research showed that the majority of respondents (78.3%) had uncontrolled glycemic control, while 21.7% of respondents achieved good target glycemic control (HbA1c less than or equal to 7.0%). This finding reflects significant challenges in diabetes management in the pediatric population, especially adolescents. Data from various international registries show that a minority of children with T1DM achieve HbA1c targets of less than 7.0%. Data from T1D Exchange in the United States showed a significant decline in glycemic control between ages 10 and 20 years. [18] Pulungan and colleagues in 2021 reported that 90% of Indonesian children with T1DM failed to achieve HbA1c less than 7.5%, showing similar glycemic control challenges as found in this research. [27]

Multiple interrelated factors likely contribute to the poor glycemic control observed in this study. First, as noted earlier, the sample was heavily weighted toward adolescent participants (53.3% aged fifteen to nineteen years), and adolescence represents the most challenging developmental period for diabetes management due to both physiological insulin resistance during puberty and psychosocial challenges with adherence and self-management.[15,18,27] Second, the majority of participants were receiving conventional insulin therapy with multiple daily injections rather than more advanced approaches such as continuous subcutaneous insulin infusion (insulin pumps) or closed-loop automated insulin delivery systems, which have been shown to improve glycemic control with reduced hypoglycemia risk but remain largely unavailable in Indonesia due to cost and access barriers.[8,14] Third, access to diabetes supplies including blood glucose monitoring strips, continuous glucose monitoring systems, and rapid-acting insulin analogs with more physiological pharmacokinetics may be limited by availability and cost, forcing compromises in management intensity.[27] Fourth, access to specialized diabetes education and support services including diabetes educators, nutritionists, and psychologists may be insufficient to provide the intensive multidisciplinary care that optimizes outcomes.[27]

Fifth, family and patient education about diabetes self-management, nutrition, exercise, and problem-solving skills may be inadequate, though all families in our study were receiving care at a tertiary center with at least some access to specialized services. Sixth, psychosocial factors including diabetes distress, anxiety about hypoglycemia, depression, eating disorders, and intentional insulin omission for weight control may interfere with adherence to recommended regimens, though we did not systematically assess these factors in this study.[28] Seventh, socioeconomic challenges affecting food security, ability to purchase medications and supplies, transportation to

medical appointments, and competing family priorities may compromise diabetes care, though again we did not collect detailed socioeconomic data to examine these relationships. Eighth, cultural factors regarding dietary patterns, family meal structure, and beliefs about illness and medical care may influence diabetes management behaviors in ways that differ from Western populations where most diabetes care models were developed.

However, it is important to acknowledge that the cross-sectional nature of our study provides only a snapshot of glycemic control at one point in time. Glycemic control fluctuates over time in response to changes in growth and development, life circumstances, motivation, and access to care, and a single HbA1c value does not necessarily predict long-term trajectories.[17] Additionally, while HbA1c represents the accepted gold standard for assessing glycemic control, it does not capture glycemic variability (frequent swings between high and low glucose levels), time in range (the proportion of time that glucose is within target), or frequency and severity of hypoglycemia, all of which contribute importantly to quality of life and possibly to complication risk beyond what is reflected in average glucose indicated by HbA1c.[29,8]

The high proportion of poor glycemic control in this research emphasizes the urgency for more intensive interventions, including more comprehensive patient and family education, closer supervision, insulin regimen adjustments, and possible use of technology such as continuous glucose monitoring and insulin pumps to facilitate achievement of better glycemic targets. [30]

Blood Pressure in Pediatric Patients with Type 1 Diabetes Mellitus

This research showed that more than half of respondents (55.0%) had normal blood pressure, 20.0% had stage 1 hypertension, 13.3% with stage 2 hypertension, and 11.7% with elevated blood pressure. Combining across the three abnormal categories, the total prevalence of any blood pressure elevation (elevated blood pressure, stage 1 hypertension, or stage 2 hypertension) in this sample was 45.0%, meaning that nearly half of children and adolescents with T1DM in this study had blood pressure measurements that exceeded normal ranges for their age and size. When focusing specifically on confirmed hypertension (combining stage 1 and stage 2), the prevalence was 33.3%, meaning that one in three participants met diagnostic criteria for hypertension. These prevalence estimates substantially exceed rates reported in general pediatric populations without diabetes, where comprehensive screening studies have found confirmed hypertension prevalence in the range of 2% to 4%, though elevated blood pressure (the pre-hypertensive category) is more common at 10% to 15% using current definitions.[31,12] Thus, the prevalence of abnormal blood pressure in our T1DM sample appears to be approximately three to four times higher than would be expected in children without diabetes of similar ages.

When comparing our findings to previous research specifically in pediatric T1DM populations, the elevated blood pressure prevalence of 45.0% appears relatively high but is within the range reported in the literature depending on study population characteristics and blood pressure measurement methods. The landmark SEARCH for Diabetes in Youth study, one of the largest epidemiological investigations of diabetes in young people in North America, estimated hypertension prevalence in pediatric T1DM ranging from 6% to 16% depending on the specific cohort and time period examined, generally lower than our findings.[6] However, studies utilizing ambulatory blood pressure monitoring, which provides more comprehensive assessment by measuring blood pressure repeatedly over twenty-four hours including during sleep, have reported even higher prevalence estimates of 14% to 30% for hypertension in pediatric T1DM, with particularly high rates of masked hypertension (normal blood pressure in clinic but elevated in daily life).[29,32] Recent data from the Australasian Diabetes Data Network

examining over six thousand adolescents and young adults with T1DM found that 19.4% met blood pressure criteria in the hypertensive range, falling between our findings and those from SEARCH.[7]

Several factors may explain why our study found relatively high prevalence of abnormal blood pressure compared to some previous reports, though entirely within the range of plausibility for this population. First, our sample was heavily weighted toward adolescents and pubertal individuals (73.3% pubertal), and blood pressure naturally increases during pubertal development, meaning that age-appropriate cutoffs for hypertension become easier to exceed during the adolescent years compared to in younger children. [25, 26] Studies with younger mean ages would be expected to find lower hypertension prevalence simply due to the age distribution. Second, our sample included high proportions of both poor glycemic control (78.3%) and relatively long diabetes duration in a subset of participants (28.3% with five or more years of diabetes), both of which are risk factors for hypertension development, potentially enriching our sample for those at higher cardiovascular risk compared to studies with better glycemic control or shorter disease duration. [6, 24]

Third, our use of digital oscillometric blood pressure measurement in the clinic setting, while following standardized protocols with multiple measurements and averaging, may be more prone to detecting isolated clinic-based blood pressure elevations (white coat hypertension) compared to ambulatory blood pressure monitoring which provides measurements in the person's natural environment throughout normal daily activities.[11,13] The American Academy of Pediatrics guidelines specifically acknowledge that oscillometric devices may systematically read higher than auscultatory measurements in some individuals, and recommend confirmation of elevated oscillometric readings with auscultatory technique, though we did not routinely perform such confirmation in our protocol.[11] Thus, some participants classified as having elevated blood pressure or hypertension based on our clinic measurements might not meet these criteria on ambulatory monitoring or repeat measurement in other settings. This possibility underscores the importance of follow-up confirmatory measurements before initiating treatment, as recommended by clinical guidelines. [11, 12]

Hypertension in children with T1DM is associated with numerous adverse outcomes both in childhood and projected into adulthood. In the short term, even modest blood pressure elevations can indicate underlying pathophysiology including endothelial dysfunction, increased arterial stiffness, activation of the renin-angiotensin-aldosterone system, increased oxidative stress, and chronic inflammation, all of which contribute to vascular damage.[33,34,35,36] In the medium term, hypertension accelerates the development and progression of microvascular complications of diabetes including diabetic nephropathy and retinopathy, creating a vicious cycle where kidney damage raises blood pressure further while elevated blood pressure accelerates kidney damage.[37,22] In the long term, hypertension in individuals with diabetes dramatically increases risk for major cardiovascular events including myocardial infarction, stroke, heart failure, and peripheral arterial disease, representing one of the most important modifiable risk factors for preventing premature cardiovascular mortality in this population.[38,36]

The high prevalence of hypertension also has important implications for clinical care delivery and screening protocols. Current guidelines from the International Society for Pediatric and Adolescent Diabetes recommend measuring blood pressure at least annually in all children with diabetes starting from the time of diagnosis, with more frequent monitoring for those with abnormal values, obesity, or evidence of kidney disease.[22] Given that we found one in three participants had hypertension using standardized measurement protocols, these recommendations appear entirely appropriate and perhaps could even argue for more

intensive screening such as biannual measurements for all and consideration of ambulatory blood pressure monitoring for those with even borderline clinic elevations to detect masked hypertension.[22,32] Healthcare systems and providers caring for pediatric diabetes populations need to ensure that blood pressure measurement is performed correctly using appropriately sized cuffs, proper technique, and age-appropriate classification systems, rather than relying on informal quick checks that may miss clinically significant elevations.

The finding of substantial hypertension prevalence also raises important questions about treatment and intervention strategies in this population. For children with diabetes and confirmed hypertension, treatment approaches include both lifestyle modifications and potentially pharmacological therapy depending on the degree of elevation and presence of target organ damage.[22,36] Lifestyle modifications include optimization of glycemic control itself (which may improve blood pressure through reduced glucotoxicity and improved endothelial function), salt restriction particularly for those with evidence of kidney disease, increased physical activity, weight management for those with overweight or obesity, and smoking cessation counseling for adolescents who smoke. Pharmacological therapy, when needed, typically begins with angiotensin-converting enzyme inhibitors or angiotensin receptor blockers, which have specific renoprotective benefits beyond blood pressure lowering and are considered first-line agents for hypertension in diabetic nephropathy.[22,36] However, initiation of antihypertensive medication in children requires careful consideration of potential side effects, cost, adherence challenges, and the possibility that some observed elevations may be transient or white coat phenomenon.

Relationship between Glycemic Control and Blood Pressure in Children with Type 1 Diabetes Mellitus

Analysis of the relationship between glycemic control and blood pressure status in this research showed that there was no relationship between glycemic control and blood pressure in pediatric T1DM patients at DR. M. Djamil Hospital Padang, with a p-value of 0.190. This aligns with research conducted by Aman B. Pulungan and colleagues on pediatric T1DM patients registered with the Pediatric Endocrinology Working Unit of the Indonesian Pediatric Society in 2012, which found no relationship between systolic and diastolic blood pressure and disease duration, age at diagnosis, and HbA1c levels. However, there was a difference in mean systolic pressure between age less than 11 years and more than 11 years, while diastolic pressure did not differ.[39]

Previous research by Chatterjee and colleagues in 2009 reported similar results, where there was no association of hypertension with HbA1c levels, finding no difference in HbA1c at enrollment and mean HbA1c during the last year between patients with masked hypertension and without masked hypertension. This research found that patients with masked hypertension had longer diabetes duration and required higher insulin doses than those without masked hypertension. [40]

A large-scale population study in China from 2011 to 2018 showed that inadequate glycemic control (HbA1c at or above 7%) increased the hazard ratio for incident hypertension by 1.54 (95% CI 1.07-2.21) compared to adequate glycemic control. [41] Research conducted by Warinpapha and colleagues in 2020 showed a relatively high frequency of masked hypertension at 27% in children with T1DM, consistent with previous research. This research for the first time assessed blood pressure phenotype using ambulatory blood pressure monitoring simultaneously with glucose levels using continuous glucose monitoring in children with T1DM.[29]

Type 1 Diabetes Mellitus in children can cause hypertension through several interrelated mechanisms. Chronic hyperglycemia, characterized by poor glycemic control, plays a central role in this process. [21, 34] Several systems involved in

blood pressure regulation in children with diabetes are disrupted, including activation of the renin-angiotensin-aldosterone system, endothelial dysfunction due to high glycemic levels, and inflammatory processes occurring both in blood vessels and kidneys. As a result of impaired insulin performance or production, glucose cannot enter cells to produce energy. Persistently high glucose levels, especially due to poor glycemic control, cause glucose to accumulate in the bloodstream. When blood with high glucose levels flows throughout the body consistently, it can cause widespread damage, including to blood vessel structures and kidney blood vessels. [42]

This finding of no statistically significant association can be interpreted with several considerations. First, the cross-sectional study design provides information only about the relationship between current glycemic control (as reflected in the most recent three months of glucose exposure through HbA1c measurement) and current blood pressure status, but cannot address temporal relationships, cumulative exposure effects, or causality. Blood pressure changes related to chronic hyperglycemia may develop over years through processes including endothelial dysfunction, arterial stiffness, kidney damage, and autonomic neuropathy, meaning that current glycemic control may be less strongly associated with current blood pressure than would be cumulative glycemic exposure over the entire diabetes duration.[34,35,20] A participant with currently good control but years of previous poor control might have sustained vascular damage manifesting as hypertension, while a participant with currently poor control but shorter diabetes duration might not yet have accumulated sufficient damage for blood pressure elevation to be clinically detectable.

Second, the HbA1c measurement, while representing the gold standard for assessing average glycemia, does not capture important dimensions of glycemic patterns that may be particularly relevant to blood pressure regulation. Specifically, HbA1c does not reflect glycemic variability (the degree of fluctuation between high and low glucose levels), time in hypoglycemic ranges, or the frequency and severity of acute hyperglycemic spikes, all of which could theoretically contribute to vascular damage and blood pressure dysregulation through mechanisms related to oxidative stress and endothelial dysfunction.[29,43] Recent research has suggested that glycemic variability may be associated with masked hypertension and non-dipping nocturnal blood pressure patterns in children with T1DM, effects that might not be captured by average glycemia alone and would not be detected by clinic blood pressure measurements.[29]

Third, the sample composition with relatively short diabetes duration in most participants (71.7% less than five years) may mean that many individuals had not yet accumulated sufficient glycemic exposure and vascular damage for hypertension to have fully manifested. The pathophysiology linking chronic hyperglycemia to elevated blood pressure operates through cumulative processes requiring time: formation of advanced glycation end products accumulates over years as proteins and lipids are non-enzymatically glycated and cross-linked; arterial stiffening from collagen glycation and smooth muscle proliferation develops gradually; endothelial dysfunction from oxidative stress and inflammation worsens progressively; and diabetic kidney disease evolves through stages of hyperfiltration, microalbuminuria, and eventually declining filtration before substantially affecting blood pressure regulation.[37,20] Therefore, the relatively short disease duration in our sample may have limited our ability to detect associations that would become more apparent with longer follow-up.

Fourth, we did not formally adjust for potential confounding variables in the primary analysis, instead using simple bivariate analysis of glycemic control versus blood pressure categories. However, numerous other factors could influence blood pressure in this population and could potentially confound the relationship with

glycemic control. Age and pubertal status profoundly affect blood pressure through growth-related increases in cardiac output and vessel caliber; nutritional status and particularly obesity directly raise blood pressure through increased blood volume, cardiac output, and insulin resistance; family history of hypertension confers genetic susceptibility; diabetes duration affects cumulative vascular damage; and various medications or supplements could affect blood pressure measurements. Another analytical approach using multivariable regression models to adjust for these covariates might reveal associations not apparent in crude bivariate analysis, though this would require larger sample sizes to avoid overfitting models with too many parameters relative to outcome events.

Study Limitations

This research has several limitations including cross-sectional design, clinic-based blood pressure measurement, relatively short disease duration, and lack of adjustment for confounding. The high prevalence of both inadequate glycemic control and abnormal blood pressure in this population, regardless of their statistical association, represents a critical clinical concern requiring comprehensive intervention approaches.

CONCLUSION

The majority of respondents were adolescents aged 15 to less than 19 years, female gender, good nutritional status, onset at age 10-14 years, disease duration less than 5 years, had entered puberty phase, and had no history of parental hypertension. Most respondents had uncontrolled glycemic control and were at high risk of experiencing both short-term and long-term complications. Nearly half of respondents experienced increased blood pressure. Patients with T1DM have a high risk of experiencing hypertension, especially those with uncontrolled glycemic control. There was no statistically significant relationship between glycemic control and blood pressure in pediatric T1DM patients.

Recommendations

Education regarding the importance of good glycemic control to prevent hypertension development through disciplined insulin use, regular exercise, maintaining ideal body weight, and checking blood pressure at least twice a year using appropriate equipment and cuffs according to guidelines. Education to children with T1DM who already experience hypertension to conduct regular blood pressure and kidney function examinations to prevent more severe complications, maintain tight blood sugar control, consume antihypertensive medications as directed by pediatric nephrologists, implement a low-salt diet, exercise regularly, and maintain ideal body weight. Future research employing longitudinal study designs, ambulatory blood pressure monitoring, detailed glycemic metrics from continuous glucose monitoring, and statistical adjustment for confounding factors will help clarify the nature and strength of relationships between glycemic exposure and blood pressure development in children with T1DM.

Declaration By Authors

Ethical Approval: Approved
Acknowledgement: None
Source of Funding: None
Conflict of Interest: No conflicts of interest declared

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How to cite this article: Putri Khairani, Eka Agustia Rini, Aumas Pabuti, Nice Rachmawati Masnadi, Asrawati Nurdin, Rahmi Lestari. Relationship between glycemic control and blood pressure in pediatric patients with type 1 diabetes mellitus at Dr. M. Djamil Hospital Padang. *International Journal of Research and Review*. 2026; 13(2): 49-62. DOI: *https://doi.org/10.52403/ijrr.20260206*

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