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QTc Prolongation among Children with Type 1 Diabetes in Northern Tanzania

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Abstract

Background: Type one diabetes mellitus is a chronic metabolic disorder characterized by insulin deficiency. T1DM predisposes to dysglycemia, which is associated with corrected QT interval (QTc) prolongation on the electrocardiogram (ECG). QTc has been identified as a potential risk factor for life-threatening cardiac arrhythmias; however, the association between QTc interval prolongation and glycemic control as well as duration of disease in children with type one diabetes mellitus (T1DM) remains unclear. **Objectives:** To determine the association between QTc interval prolongation and both glycemic control and disease duration among children with Type one diabetes mellitus receiving care at KCMC. **Methods:** A hospital-based matched comparative cross-sectional study of children below 18 years, diagnosed with T1DM was conducted at a pediatric diabetic clinic from October 2023 to May 2024. Patients' demographic and clinical data, including duration of disease and glycosylated hemoglobin (HbA1c) levels, were collected. Resting 12-lead ECGs were recorded for each participant, and the QT interval corrected for heart was measured using the Bazett's formula. QTc interval prolongation was defined as a QTc value greater than 440 milliseconds. The data were analyzed using Stata version 17. Pearson's correlation coefficient was used to assess the association between QTc interval and HbA1c levels and disease duration. Conditional logistic regression was used to estimate the matched odds ratio (mOR) for the association between T1DM status and QTc interval. A p-value of less than 0.05 was considered statistically significant. **Results:** A total of 88 children, 44 with T1DM and 44 individually age- and sex-matched healthy controls, were analyzed; the proportion of QTc interval prolongation was 22.7% in T1DM. After accounting

for individual matching by age and sex, T1DM patients had significantly five times the odds of prolonged QTc compared with controls (matched OR = 5.0, 95% CI: 1.09 - 22.81, p = 0.038). There was a significant positive correlation between continuous QTc interval and mean HbA1c levels (r = 0.38, p = 0.01), whereas no statistically significant correlation was observed between QTc interval and duration of disease (r = 0.15, p = 0.31). **Conclusion:** QTc interval prolongation was observed among children with type 1 diabetes mellitus (T1DM), with a significant association between QTc duration and glycemic control. These findings suggest that poorer glycemic control may be associated with altered cardiac repolarization in children with T1DM. Further longitudinal studies are warranted to establish the clinical significance of these findings and determine whether improved glycemic control influences QTc duration and subsequent arrhythmic risk.

Keywords

Children, Type One Diabetes Mellitus, QTc Interval, Glycemic Control

1. Introduction

Type one diabetes mellitus is an autoimmune condition of global health concern affecting around 8.4 million people worldwide about 1.5 million younger than 20 years, and the number is expected to rise substantially by 2040 [1]. Children with T1DM face an elevated risk of cardiovascular complications such as arrhythmias and cardiac autonomic neuropathy (CAN), which can be picked early via electrocardiogram (ECG) changes, such as QT interval prolongation [2].

The QT interval on an ECG captures ventricular depolarization and repolarization. Prolongation of the QTc interval can cause premature action potentials during the late phase of depolarization. This increases the risks of Torsades de Pointes, a form of ventricular arrhythmia, invariably in the context of dysglycemia, genetic traits, and environmental influences [3]. Prolongation of the QTc interval has been connected to life- threatening arrhythmias and sudden death [4] [5].

Recent estimates suggest that the rate of sudden unexplained death among childhood-onset Type 1 diabetes ranges from 45 to 48 per 100,000 patient-years [4].

Duration of T1DM is stipulated in the progression of cardiovascular complications. In 2022, the International Society for Pediatric and Adolescent Diabetes (ISPAD) recommended screening for diabetes-related microvascular complications, including peripheral neuropathy in T1DM patients from the age of 11 within 2 to 5 years from diagnosis, and follow up annually by physical examination and clinical testing [6].

On the other hand, the American Diabetes Association recommends glycemic control monitoring for cardiovascular disease by measuring serum hemoglobin A1c (HbA1c) at least every 90 days targeting at <7.5% [7].

In Sub-Saharan Africa, where late diagnoses, limited access to monitoring and treatment are common, glycemic control is seldom achieved thereafter children with T1DM may experience cardiovascular complications rather earlier [8] [9]. Nonetheless there is lack of data in this region and Tanzania in particular [10].

2. Methods

A hospital-based matched comparative cross-sectional study enrolled 44 children with type 1 diabetes mellitus (T1DM) who had been receiving insulin therapy for more than one year and were attending the Pediatric Diabetes Clinic at Kilimanjaro Christian Medical Centre (KCMC), Northern Tanzania, between October 2023 and May 2024. An additional 44 healthy children aged 4 - 17 years were recruited as controls using individual matching based on age and sex, whereby each child with T1DM was matched to one healthy control of the same sex and within an age tolerance of ±1 year, resulting in a 1:1 matching ratio. Healthy controls were recruited through convenience sampling from eligible volunteers, including children of hospital staff, relatives, and acquaintances associated with KCMC. Written informed consent/assent was obtained from parents or guardians of all participants before enrolment.

The exclusion criteria applied to both children with type 1 diabetes mellitus (T1DM) and healthy controls included electrocardiographic abnormalities affecting ventricular depolarization or indicating pre-excitation; acute infections or other acute or chronic illnesses that could influence cardiovascular function; hypertension or known cardiorespiratory disease; electrolyte disturbances involving serum sodium, potassium, calcium, or magnesium; known thyroid disease, malignancy, or uremia; a family history of sudden cardiac death in a first-degree relative; and the use of medications or substances known to prolong the QT interval or affect cardiac function within one week prior to recruitment.

Data collection included detailed history and physical examination, blood pressure measurements, and blood sampling to assess various biochemical markers like serum potassium, sodium, and calcium. Glycemic control was assessed using the arithmetic mean of the three most recent consecutive HbA1c measurements obtained at approximately three-month intervals before electrocardiographic assessment. The mean HbA1c value was calculated for each participant and used as a continuous variable in the correlation analysis with QTc interval duration. For descriptive purposes, mean HbA1c values were additionally categorized into predefined glycemic control groups. BMI was calculated using WHO standards. Electrocardiograms (ECGs) were performed to assess the QTc interval. The standard 12-lead ECG was recorded at 25 mm/s, along with a Lead II rhythm strip at 50 mm/s; both QT and RR intervals were measured. The QT interval was defined from the onset of the QRS complex to the end of the T wave. The end of the QT interval was identified as the point where a tangent drawn along the steepest downslope of the dominant repolarization wave intersected with the isoelectric

line. Lead II was prioritized for QTc measurement. Three separate measurements were taken from each ECG, and the average of these values was used as the final QTc measurement. The corrected QT (QTc) interval was calculated using Bazett's formula, and QTc prolongation was operationally defined as a value greater than 440 milliseconds. This threshold was selected based on previous studies involving children and adolescents with type 1 diabetes mellitus, particularly those by Suys *et al.* [11]. and Galli-Tsinopoulou *et al.* [12], which employed comparable thresholds to investigate ventricular repolarization abnormalities in pediatric diabetic populations. Furthermore, pediatric electrocardiographic literature recognizes QTc values around 440 milliseconds as an upper boundary of the conventional normal range, although values between 440 and 460 milliseconds may be considered borderline depending on the clinical reference, age, sex, and correction method [13]. Therefore, the threshold of >440 milliseconds were retained to facilitate comparison with earlier pediatric T1DM studies and to identify potentially altered ventricular repolarization, rather than to establish a diagnosis of congenital long QT syndrome or predict clinically significant arrhythmias. The study aimed to examine how factors such as glycemic control, insulin dose, and other clinical variables affects the QTc interval in children with T1DM. Blood glucose levels were also monitored through fasting blood sugar tests, and all procedures followed strict protocols to ensure accurate data collection.

3. Data Management and Analysis

Data were coded, entered, cleaned, and analyzed using Stata version 17. Categorical variables were summarized using frequencies and percentages, while continuous variables were summarized as mean and standard deviation.

The distribution of continuous variables was assessed using the Shapiro-Wilk test and No statistically significant departures from normality were detected for the variables assessed. Pearson's chi-square test was used to examine differences in the distribution of categorical baseline characteristics between patients with type 1 diabetes mellitus (T1DM) and healthy controls. Among children with T1DM, Pearson's correlation coefficient was used to assess the linear association between continuous QTc interval duration and the arithmetic mean of the three most recent HbA1c measurements, obtained at approximately three-month intervals before ECG assessment. Pearson's correlation coefficient was also used to examine the association between continuous QTc interval duration and diabetes duration in years.

QTc interval was analyzed continuously, while QTC interval prolongation as a binary variable. Given that patients with T1DM and healthy controls were individually matched by age and sex at a ratio of 1:1, conditional logistic regression was used to estimate the matched odds ratio (mOR) and corresponding 95% confidence interval (CI) for the association between T1DM status and QTc interval. Matching was accounted for by specifying the matched-pair identification

variable as the grouping variable in the conditional logistic regression model. Age and sex were not additionally included as covariates because they were the matching factors. A p-value of less than 0.05 was considered statistically significant.

4. Results

4.1. Baseline Characterisitcs of Study Participants

The baseline data of participants consisted of 88 children, 44 with T1DM, and 44 age- and sex-matched healthy controls. Their average age was 11.6 years with a standard deviation of 3.5 years, and age groups were categorized into children below or equal to 11 years and those above 11 years. Most (53.4%) were above 11 years old, the majority were female (52.3%), 47.7% were in pubertal stages, and 71.59% had a normal BMI.

Among the T1dm, the majority (72.7%) had disease duration of T1DM below 5 years. Most of the T1dm (47.7%) presented with HbA1C (>10 - 12.5), and likewise, 47.7% had an insulin dose per kg/day of 0.8 - 1.2 IU. There was no significant difference between T1dm and controls with regards to sex, age, blood pressure, BMI, or pubertal staging (Table 1).

Table 1. Baseline characteristics of study participants (N = 88).

Variable	Total	T1dm (n = 44) n (%)	Controls (n = 44) n (%)	p-value
Age (years)				0.83
≤11	41	20 (45.5)	21 (47.7)	
>11	47	24 (54.5)	23 (52.3)	
Mean ± SD		11.7 ± 4.0	11.4 ± 4.0	
Min - Maximum		5.0 - 17.0	5.0 - 17.0	
Sex				1.00
Male	42	21 (47.7)	21 (47.7)	
Female	46	23 (52.3)	23 (52.3)	
Systolic blood pressure (mmHg)				0.56
Mean ± SD		106.2 ± 14.5	104.0 ± 12.2	
Diastolic blood pressure (mmHg)				0.20
Mean ± SD		69.0 ± 12.8	66.0 ± 10.2	
Disease duration (years)				
≤5	32	32 (72.7)	-	
>5	12	12 (27.3)	-	
Insulin dose/kg/day (IU)				
<0.8	10	10 (22.7)	-	
0.8 - 1.2	21	21 (47.7)	-	
>1.2	13	13 (29.5)	-	

Continued

Tanner				0.34
Pre pubertal (Tanner 1)	25	10 (22.7)	15 (34.1)	
Pubertal (Tanner 2 - 4)	42	22 (50.0)	20 (45.5)	
Postpubertal (Tanner 5)	21	12 (27.3)	9 (20.5)	
BMI (Kg/M²)				0.66
Obesity	1	0 (0.0)	1 (2.3)	
Overweight	16	9 (20.5)	7 (15.9)	
Normal	63	31 (70.5)	32 (72.7)	
Thinness	7	3 (6.8)	4 (9.1)	
Severe thinness	1	1 (2.3)	0 (0.0)	
HBAIC (%)				
<7.5	0	0 (0.0)	-	
7.5 - 10	14	14 (31.8)	-	
>10 - 12.5	21	21 (47.7)	-	
>12.5	9	9 (20.5)	-	

4.2. The Proportion of QTc Interval Prolongation among Children with T1DM

During the study, the proportion of QTc interval prolongation among children with T1DM was analyzed. 22.7% of children presented with QTc interval prolongation, while among controls, 4.5% presented with QTc interval prolongation.

After accounting for individual matching by age and sex, T1DM patients had significant five times the odds of prolonged QTc compared with controls (matched OR = 5.0, 95% CI: 1.09 - 22.81, p = 0.038) (Table 2).

Table 2. Association of prolonged QTc interval among T1dm and controls (N = 88).

Variable	Prolonged QTc interval	matched OR (95% CI)	p-value
T1dm	10 (22.7)	5.0 (1.09 - 22.81)	0.038
Controls	2 (4.5)	Ref	

4.3. Association of QTc Interval Prolongation and Glycemic Control among Children with T1DM

Among children with T1DM, Pearson's correlation analysis demonstrated a statistically significant moderate positive correlation between continuous QTc interval duration and the mean of three consecutive HbA1c measurements obtained at approximately three-month intervals (r = 0.38, p = 0.01). This finding indicates that higher mean HbA1c levels were associated with longer QTc intervals (Figure 1).

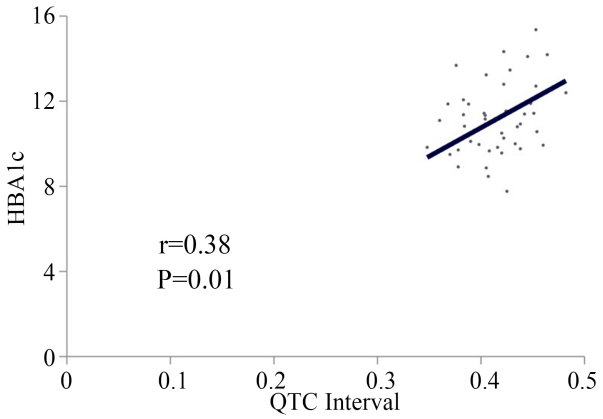


Figure 1. Association of QTc interval prolongation and glycemic control among children with T1 DM (n = 44).

4.4. Association of QTc Interval and Duration of Disease among Children with T1DM

Meanwhile, among children with T1DM the univariate correlation analysis between QTc interval and disease duration showed a weak positive correlation, which was not statistically significant (**Figure 2**).

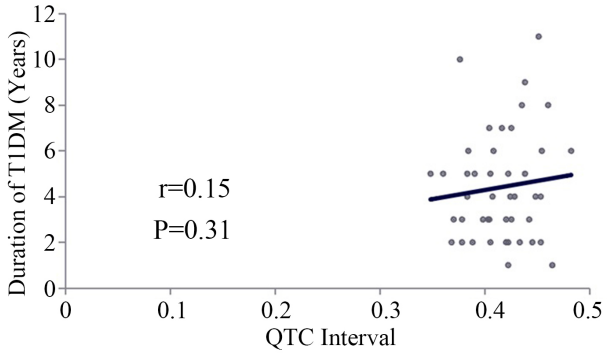


Figure 2. Association between QTc interval and duration of DM in T1DM children (n = 44).

5. Discussion

This study demonstrated that QTc interval prolongation was present in 22.7% of children with type 1 diabetes mellitus (T1DM), with approximately fivefold higher odds compared with age- and sex-matched healthy controls. This finding highlights the occurrence of ventricular repolarization abnormalities in a proportion of children with T1DM, even in the absence of clinically recognized cardiovascular complications. The observed proportion was comparable to previously reported estimates of 23.3% and 19.4% [11] [12], although higher and lower proportions of 33.3% and 10%, respectively, have also been documented [13]-[15]. Such variations may reflect differences in glycemic control, disease characteristics, acute metabolic disturbances, and the methods and thresholds used to assess QTc prolongation. In particular, the influence of acute metabolic decompensation and subsequent

treatment may contribute to differences between studies involving clinically stable children and those assessed during diabetic ketoacidosis [16] [17].

The greater odds of QTc prolongation observed among children with T1DM compared with healthy controls are consistent with earlier reports of altered ventricular repolarization in pediatric diabetes [12]. More recent findings provide additional evidence supporting this observation [18]. The investigators reported significantly higher QTc measurements, QTc dispersion, and other ventricular repolarization parameters among children with T1DM, although QTc values remained within normal ranges. These findings suggest that subtle electrophysiological differences may occur before conventional criteria for QTc prolongation are met. While the present study identified a greater proportion of children exceeding the QTc threshold of 440 milliseconds, the recent study highlights the broader spectrum of ventricular repolarization changes that may accompany pediatric diabetes. Nevertheless, differences in electrocardiographic parameters do not necessarily establish clinically significant arrhythmia risk, and longitudinal evidence is required to determine their prognostic implications.

A particularly important observation in the present study was the increasing proportion of QTc prolongation with worsening glycemic control. QTc prolongation was identified in 7.1% of children with HbA1c levels of 7.5% - 10%, compared with 23.8% among those with HbA1c levels above 10% - 12.5% and 44.4% among those with HbA1c levels above 12.5%. This progressive increase suggests that poorer long-term glycemic control may be associated with a greater likelihood of ventricular repolarization abnormalities. The finding is consistent with earlier studies reporting positive associations between HbA1c and QTc abnormalities [14] [19] although other investigations have reported weaker or statistically nonsignificant relationships [11]. Notably, Özdemir Şahan *et al.* [18] also found no significant correlation between HbA1c and the electrocardiographic parameters examined, despite identifying significant differences between children with diabetes and healthy controls. These contrasting findings suggest that the relationship between glycemic control and ventricular repolarization may be more complex than a direct linear association.

Differences in the measurement of glycemic exposure may partly explain these inconsistencies. In the present study, glycemic control was assessed using the mean of three consecutive HbA1c measurements obtained approximately three months apart, providing a broader assessment of recent glycemic exposure than a single HbA1c measurement. Nevertheless, this approach does not fully capture glycemic variability, recurrent hypoglycemia, or long-term cumulative glycemic exposure. Recent prospective evidence from Bergdahl *et al.* [20] provides further insight into this relationship. In children with relatively well-regulated T1DM, the investigators found no significant overall differences in cardiac autonomic markers compared with healthy controls. However, QT variability index was associated with longitudinal glycemic exposure and other metabolic characteristics, suggesting that aspects of ventricular repolarization may be influenced by cumulative glycemic

patterns rather than a single measure of HbA1c. Although QT variability index differs from QTc duration, these findings support the importance of considering both the magnitude and duration of glycemic exposure when interpreting electrocardiographic abnormalities in children with T1DM.

The potential contribution of autonomic dysfunction to ventricular repolarization abnormalities is also supported by recent research. Gözüküçük *et al.* [21], studying children with persistently poor metabolic control, identified reduced heart rate variability, abnormal orthostatic responses, and impaired ventricular diastolic function despite the absence of overt cardiovascular symptoms. These findings suggest that subclinical cardiovascular autonomic abnormalities may be detectable in children with longstanding poor glycemic control. Conversely, Bergdahl *et al.* [20] found no manifest evidence of cardiac autonomic neuropathy in a comparatively well-regulated pediatric cohort, although children with higher body mass index demonstrated less favorable QT variability measurements. Considered together, these studies suggest that metabolic control and other clinical characteristics may influence the development or expression of subclinical cardiovascular abnormalities. They also demonstrate that autonomic dysfunction is not an inevitable finding in children with T1DM. Importantly, the present study assessed QTc prolongation using resting electrocardiography and did not include direct autonomic function testing. Therefore, the observed abnormalities cannot be attributed specifically to cardiac autonomic neuropathy.

In contrast to glycemic control, diabetes duration was not significantly associated with QTc prolongation in the present study. Although prolonged QTc was observed in 33.3% of children with diabetes duration exceeding five years compared with 18.8% of those with shorter disease duration, this difference was not statistically conclusive. The finding is consistent with earlier research reporting weak or nonsignificant relationships between diabetes duration and QTc measurements [12], but differs from studies describing stronger positive associations [14]. The more recent study [18], similarly reported no significant association between diabetes duration and the evaluated electrocardiographic parameters. In contrast, Bergdahl *et al.* [20] identified an association between diabetes duration and QT variability index, indicating that cumulative disease exposure may influence electrophysiological characteristics not fully represented by QTc duration alone. These differences emphasize the importance of distinguishing between conventional QTc prolongation and other measures of repolarization instability. The absence of a significant association in the present study may also reflect limited statistical power, particularly because relatively few participants had longer disease duration.

The observation that glycemic control was associated with QTc prolongation whereas diabetes duration was not may suggest that metabolic exposure is relevant to ventricular repolarization beyond the number of years since diagnosis [22]. Children with similar diabetes duration may experience markedly different glycemic trajectories and consequently may not have equivalent cumulative exposure to

hyperglycemia. This interpretation is compatible with recent evidence examining longitudinal glycemic measures and autonomic markers [20]. However, the present study does not permit determination of whether poor glycemic control preceded the QTc abnormalities or whether improvements in glycemic control would reverse them. These questions require longitudinal investigation with repeated electrocardiographic and glycemic assessments.

Sex-related differences were also observed, with female participants demonstrating a higher proportion of QTc prolongation than males. However, this association was not statistically significant (OR 2.62; $p = 0.21$), and the estimate was imprecise. Previous studies have described differences in ventricular repolarization associated with sex and pubertal maturation [23] potentially reflecting physiological changes in cardiac electrophysiology during adolescence [24] [25]. Nevertheless, the present findings do not establish an independent sex-related association with QTc prolongation. Furthermore, the limited number of prolonged-QTc events restricts the reliability of subgroup comparisons. Therefore, these results should be interpreted as exploratory rather than as evidence supporting different clinical surveillance strategies for male and female patients.

The clinical interpretation of these findings requires consideration of the distinction between an electrocardiographic abnormality and an established cardiovascular complication. QTc prolongation has been associated with ventricular arrhythmias and adverse cardiovascular outcomes in certain clinical settings [4] [26] but a prolonged QTc measurement alone does not confirm cardiac autonomic neuropathy or predict future arrhythmic events in an individual child. Recent studies have employed additional methods, including heart rate variability, baroreceptor sensitivity, orthostatic testing, and QT variability measurements, to investigate subclinical cardiovascular changes more comprehensively [20] [21]. These approaches may help clarify the mechanisms underlying QTc abnormalities and distinguish transient repolarization changes from persistent autonomic dysfunction. Although resting electrocardiography is accessible and noninvasive, the present findings do not establish that routine QTc screening reduces arrhythmic events or mortality.

To our knowledge, this is among the first studies in Tanzania to evaluate QTc interval prolongation among children with T1DM. The findings provide preliminary evidence on the burden of QTc prolongation in this pediatric population.

Several limitations should be considered when interpreting the findings of this study. First, the relatively small sample size, particularly the limited number of participants with prolonged QTc intervals, reduced statistical power to detect modest but potentially clinically meaningful associations and limited the reliability of subgroup analyses, including sex-related comparisons. There is inability to adequately adjust for potential confounding in the association between HbA1c and QTc interval. Although contemporaneous random blood glucose, age and pubertal status were considered in an exploratory multivariable analysis, the small number of participants with QTc prolongation and sparse data across predictor

categories resulted in model instability and prevented reliable adjusted estimates. Additionally, electrolyte levels were not incorporated into the final analysis. Therefore, the observed HbA1c and QTc association should be interpreted as an unadjusted association, and residual confounding cannot be excluded. Second, healthy controls were recruited through convenience sampling, potentially introducing selection bias and limiting the generalizability of the findings. Although individual matching at a 1:1 ratio based on sex and age (±1 year) was employed to enhance comparability between children with T1DM and healthy controls, residual confounding from other measured and unmeasured factors, including contemporaneous glycemic status and pubertal development, cannot be excluded. Furthermore, individual matching does not eliminate potential differences in other clinical and physiological characteristics between the groups. Third, QTc prolongation was defined using a uniform threshold of >440 ms, which may not fully account for age-, sex-, and puberty-related variations in QTc duration, potentially influencing the classification of QTc prolongation. In addition, QTc was assessed using a resting electrocardiogram, which provides a measurement at a single point in time and may not capture temporal fluctuations in ventricular repolarization. The use of Bazett's correction may also introduce measurement variability, particularly at higher or lower heart rates. Finally, the study design limits the ability to fully establish temporal or causal relationships between glycemic control, diabetes duration, and QTc prolongation. Because cardiac autonomic function and subsequent arrhythmic outcomes were not directly assessed, QTc prolongation should be interpreted as an electrocardiographic finding rather than definitive evidence of cardiac autonomic neuropathy or future arrhythmic risk.

6. Conclusion

In conclusion, children with type 1 diabetes mellitus had approximately fivefold higher odds of QTc interval prolongation compared with age- and sex-matched healthy controls. Poorer glycemic control was associated with a higher prevalence of QTc prolongation, suggesting a potential relationship between chronic hyperglycemia and altered ventricular repolarization. Although QTc prolongation was more frequent among female participants, the observed difference was not statistically significant. No statistically significant association was observed between diabetes duration and QTc prolongation. Given the relatively small sample size, these findings should be interpreted cautiously. Larger prospective studies are warranted to clarify these associations and determine their clinical significance.

Availability of Data and Materials

The dataset used and/or analyzed during the study are available from the corresponding author on request.

Ethical Consideration

The ethical clearance was obtained from the Kilimanjaro Christian Medical Univer-

sity College research ethics committee No.PG 183/2023.

Conflicts of Interest

The authors declare no conflict of interest.

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