

Prevalence of Diabetic Retinopathy in Children Aged ≥ 10 Years with Type 1 Diabetes Mellitus Attending the Diabetic Clinic at Kassala Teaching Hospital, Sudan: A Cross-Sectional Study, August–December 2025

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Abstract

Background: Diabetic retinopathy (DR) is a leading microvascular complication of diabetes mellitus and a major cause of preventable visual impairment. Although traditionally considered an adult disease, DR is increasingly recognized among children and adolescents with diabetes. Early detection and management are essential to prevent irreversible vision loss. However, in Sudan, limited data exist on the prevalence and risk factors of DR among pediatric diabetic patients.

Method: A descriptive, cross-sectional, hospital-based study was conducted at the Diabetic Clinic of Kassala Teaching Hospital from August to December 2025. The study included 115 children aged over ten years diagnosed with type 1 diabetes. Data were collected using a structured, interview-administered questionnaire and clinical examination, including fundus evaluation. Statistical analysis was performed using SPSS version 26 to assess frequencies and associations between diabetic retinopathy and relevant demographic and clinical factors.

Result: The study included 115 participants, of whom 60.9% were females and 39.1% were males. The prevalence of diabetic retinopathy was 1.7%, with two cases identified: one mild non-proliferative DR and one moderate non-proliferative DR with clinically significant macular edema. Poor glycemic control was common, with 51.3% of participants having HbA1c levels above 10%. Most participants (96.5%) had never undergone previous eye screening. No statistically significant associations were found between diabetic retinopathy and glycemic control ($p = 1.000$), duration of diabetes ($p = 0.534$), age group ($p = 0.119$), or gender ($p = 1.000$). However, the very small number of DR cases substantially limited the statistical power to detect associations.

Conclusion:

The prevalence of DR in our study was low (1.7%). Nevertheless, DR was identified in two children, including one with severe NPDR and DME. The high frequency of suboptimal glycemic control and the very low uptake of previous retinal screening highlight important gaps in pediatric diabetes eye care. Larger prospective studies are needed to better characterize the burden and risk factors of DR among children with diabetes in Sudan.

Background

Diabetic retinopathy (DR) is one of the most common and vision-threatening microvascular complications of diabetes mellitus (DM). It develops as a result of chronic hyperglycemia, which causes progressive damage to the retinal capillaries, arterioles, and venules, eventually leading to retinal ischemia, increased vascular permeability, and pathological neovascularization. If left undetected or untreated, DR may progress from non-proliferative to proliferative stages, resulting in irreversible visual impairment or blindness. Although traditionally regarded as a complication affecting adults with longstanding diabetes, growing evidence suggests that DR can also occur in children and adolescents, particularly those with type 1 diabetes mellitus (T1DM), making it an important cause of preventable

vision loss in young populations worldwide [1, 2]. The development of DR is driven by a complex interaction of metabolic, inflammatory, and vascular mechanisms. Persistent hyperglycemia promotes oxidative stress, endothelial dysfunction, and chronic inflammation, leading to retinal microvascular damage and disruption of the blood-retinal barrier [3, 4]. Several factors have been consistently associated with the onset and progression of DR, including longer duration of diabetes, poor glycemic control, hypertension, dyslipidemia, nephropathy, obesity, puberty, pregnancy, and genetic susceptibility [5]. In addition, socioeconomic factors, limited access to healthcare services, and poor awareness of diabetic eye disease contribute to delayed diagnosis and disease progression, particularly in low-resource settings. The global prevalence of diabetes continues to increase across all age groups, including children and adolescents, largely due to changing lifestyles, increasing obesity, and unhealthy dietary habits [6]. Although T1DM remains the predominant form of diabetes in childhood, the incidence of type 2 diabetes mellitus (T2DM) has increased considerably in recent years, accounting for a substantial proportion of newly diagnosed pediatric diabetes cases in some countries [7]. Consequently, the number of children at risk of developing early diabetic complications, including DR, has also increased. Recent studies have demonstrated that DR may develop only a few years after the diagnosis of diabetes in children. A cohort study from the United States reported that 20.1% of children with T1DM and 7.2% of those with T2DM developed DR during a median follow-up period of three years [7]. Worldwide, the reported prevalence of DR among children and adolescents with diabetes ranges from 2.3% to 57.6%, reflecting differences in study populations, screening methods, and diagnostic criteria [8–10]. Considerable regional variation has also been reported, with prevalence estimates ranging from 12.5% in Southeast Asia to 36.3% in the Western Pacific region. In Wales, a large population-based study involving 4,172 individuals diagnosed with T1DM before the age of 18 years found that 26.7% had background DR, 10.7% had referable DR, and 4.1% had proliferative DR [11]. Several clinical and demographic characteristics have been associated with the development of DR in children and adolescents, including increasing age, longer duration of diabetes, persistently elevated HbA1c levels, hypertension, dyslipidemia, obesity, and hormonal changes during puberty [12]. Emerging evidence also highlights the contribution of chronic systemic inflammation and endothelial dysfunction to retinal microvascular injury. Nevertheless, the reported risk factors vary across populations, emphasizing the importance of conducting locally relevant studies to better understand the epidemiology of DR in different healthcare settings. In Sudan, pediatric diabetes management is challenged by limited access to specialized care, inadequate screening, and low awareness of diabetic eye disease, potentially leading to delayed detection of diabetic retinopathy (DR). Despite its clinical importance, data on DR among children and adolescents in Sudan, particularly in Eastern Sudan, remain limited. Therefore, this study aims to determine the prevalence of DR among children and adolescents with type 1 diabetes attending the Diabetic Clinic at Kassala Teaching Hospital in 2025, identify associated risk factors, including age, diabetes duration, and glycemic control, and assess current screening practices. The findings may help inform strategies for early detection and improve pediatric diabetic eye care in Sudan [13]

Methods

Study design and setting A hospital-based cross-sectional study was conducted between August and December 2025 at the Diabetic Clinic of Kassala Teaching Hospital, Kassala State, eastern Sudan. Kassala Teaching Hospital is the main tertiary referral center providing specialized pediatric endocrinology and ophthalmic services for patients from Kassala State and neighboring regions.

Study population The study included children aged ≥ 10 years with a confirmed diagnosis of type 1 diabetes mellitus (T1DM) who attended the diabetic clinic during the study period.

Inclusion criteria Age ≥ 10 years; Confirmed diagnosis of T1DM; and Written informed consent obtained from a parent or legal guardian, together with assent from the participating child.

Exclusion criteria Ocular diseases other than diabetic retinopathy that could interfere with retinal assessment (e.g., congenital cataract, anterior segment dysgenesis, or high myopia); Previous intraocular surgery or retinal laser photocoagulation; Systemic diseases unrelated to diabetes that could independently affect the retinal vasculature; or Incomplete clinical records or inconclusive ophthalmic examination findings.

Data collection Data were collected using a structured interviewer-administered questionnaire completed by the principal investigator. The questionnaire included demographic characteristics, diabetes-related history, ophthalmic screening practices, and clinical variables. Laboratory and clinical data, including glycated hemoglobin (HbA1c) levels and blood pressure measurements, were extracted from patients' medical records whenever available.

Operational definitions Glycemic control: Categorized according to the most recent HbA1c measurement obtained within three months before or at the study visit. Hypertension: Defined as a documented diagnosis of hypertension or blood pressure above the 95th percentile for age, sex, and height on at least three separate measurements. Hyperlipidemia: Defined as a documented history of dyslipidemia or abnormal fasting lipid profile. Regular ophthalmic screening: Defined as undergoing at least one dilated fundus examination annually. Screening was considered irregular if examinations were performed only after the onset of visual symptoms or had never been performed. **Ophthalmic examination and diabetic retinopathy grading** All participants underwent a comprehensive ophthalmic examination. Pupillary dilatation was achieved using topical tropicamide 1% and phenylephrine 2.5%. A dilated fundus examination was then performed using direct and indirect ophthalmoscopy by the principal investigator. All retinal findings were independently reviewed and confirmed by a senior consultant ophthalmologist. Eyes with clinical suspicion of diabetic macular edema or uncertain macular findings underwent optical coherence tomography (OCT) to confirm or exclude macular involvement. Diabetic retinopathy was graded according to the International Clinical Diabetic Retinopathy Disease Severity Scale as no diabetic retinopathy, mild, moderate, or severe non-proliferative diabetic retinopathy (NPDR), and proliferative diabetic retinopathy (PDR). Diabetic macular edema (DME) was diagnosed based on clinical examination and confirmed by OCT when clinically indicated.

Sample size and sampling The minimum required sample size was calculated using Cochran's formula for estimating a single population proportion:

$$n = Z^2 p(1-p) / d^2.$$

where n is the required sample size, Z is the standard normal deviate corresponding to a 95% confidence level (1.96), p is the expected prevalence of diabetic retinopathy (0.05), and d is the desired precision (0.04). The calculated minimum sample size was 115 participants. Consecutive eligible patients attending the diabetic clinic during the study period were invited to participate until the end of the study period.

Bias control Selection bias was minimized by recruiting consecutive eligible patients throughout the study period. Observer bias was reduced by using a standardized retinal examination protocol and independent confirmation of retinal findings by a senior consultant ophthalmologist. Whenever possible, participants' responses regarding diabetes duration and previous ophthalmic screening were verified using hospital medical records. Analyses involving variables with missing values were performed using complete-case analysis.

Statistical analysis Data were analyzed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Categorical variables are presented as frequencies and percentages, whereas continuous variables are presented as means $\pm$ standard deviations (SD) or medians with interquartile ranges (IQR), depending on data distribution assessed using the Shapiro–Wilk test. Associations between potential risk factors and diabetic retinopathy were assessed using the Chi-square test or Fisher's exact test for categorical variables and the independent-samples t-test or Mann–Whitney U test for continuous variables, as appropriate. Variables with a p-value <0.20 in the univariable analysis were entered into a multivariable binary logistic regression model. Adjusted odds ratios (AORs) with 95% confidence intervals (CIs) were reported. All statistical tests were two-sided, and a p-value <0.05 was considered statistically significant.

Ethical considerations Ethical approval was obtained from the Ethics Review Committee of the Sudan Medical Specialization Board and the Research Ethics Committee of the Education Development Center (EDC) before study commencement. The study was conducted in accordance with the principles of the Declaration of Helsinki. Written informed consent was obtained from the parents or legal guardians of all participants, and assent was obtained from all participating children. Participant confidentiality was maintained by assigning unique study identification codes and anonymizing all collected data. Participation was voluntary, and refusal to participate or withdrawal from the study did not affect routine medical care.

Results

A total of 115 children with type 1 diabetes mellitus (T1DM) were included in the study. The demographic, clinical, and ophthalmic characteristics of the participants were assessed. The mean age

distribution, sex distribution, duration of diabetes, glycemic control status, diabetes management practices, and ophthalmic findings are presented in the following tables. The age distribution showed that 44 participants (38.3%) were aged 10–13 years, 31 (27.0%) were aged 14–16 years, and 40 (34.8%) were aged 17–18 years. Females represented 70 (60.9%) of the participants, while males represented 45 (39.1%)

Table 1. Demographic characteristics of children with type 1 diabetes mellitus (n=115) Characteristic Category n %

Age group	10–13 years	44	38.3
Age group	14–16 years	31	27
Age group	17–18 years	40	34.8
Gender	Female	70	60.9
Gender	Male	45	39.1

Regarding diabetes-related characteristics, 39 participants (33.9%) had diabetes duration of more than five years. The most common HbA1c category was 7–9% (43 participants, 37.4%), while only 13 participants (11.3%) had HbA1c levels below 7%. Difficulty maintaining good glycemic control was reported by 71 participants (61.7%).

Table 2. diabetes duration and glycemic control characteristics among children with type 1 diabetes mellitus (n=115). Characteristic Category n %

Characteristic Category n %			
Duration of diabetes	<1 year	22	19.1
Duration of diabetes	1–2 years	24	20.9
Duration of diabetes	3–5 years	30	26.1
Duration of diabetes	>5 years	39	33.9
Last recorded HbA1c level	<7%	13	11.3
Last recorded HbA1c level	7–9%	43	37.4
Last recorded HbA1c level	10–12%	33	28.7
Last recorded HbA1c level	>12%	26	22.6
Frequency of blood glucose monitoring	Once daily	29	25.2
Frequency of blood glucose monitoring	Two to three times per week	51	44.3
Frequency of blood glucose monitoring	Once weekly	8	7
Frequency of blood glucose monitoring	Rarely or never	27	23.5
Following prescribed diabetes medication plan	YES	57	49.6
Following prescribed diabetes medication plan	NO	58	50.4
Difficulty maintaining good glycemic control	YES	71	61.7
Difficulty maintaining good glycemic control	No	44	38.3

Ophthalmic symptoms were reported by 18 participants (15.7%), with blurred vision being the only reported symptom. None of the participants had been previously diagnosed with diabetic retinopathy. Routine diabetic retinopathy screening was uncommon, with 111 participants (96.5%) reporting no previous screening. A family history of diabetic retinopathy was reported by 12 participants (10.4%). Hypertension was present in only one participant (0.9%), while no participants reported hyperlipidemia or other diabetes-related complications

Characteristic Category n %			
Eye-related symptoms during the previous year	Blurred vision	18	15.7
Eye-related symptoms during the previous year 97 84.3	No eye-related symptoms	97	84.3
Previous diagnosis of diabetic retinopathy	Yes	0	0.0
Family history of diabetic retinopathy	Yes	12	10.4
Family history of diabetic retinopathy	No	103	89.6
Hypertension	Yes	1	0.9
Hypertension	No	114	99.1
Hyperlipidemia 0 0.0	Yes	0	0.0
Other diabetes-related complications (renal or neurological)	Yes	0	0.0
Monthly diabetic clinic follow-up	Yes	115	100

Dilated fundus examination revealed diabetic retinopathy in two participants (1.7%). Both affected participants had a diabetes duration of more than 10 years. The first participant was 18 years old and had moderate non-proliferative diabetic retinopathy with diabetic macular edema, characterized by retinal hemorrhages, exudates, and macular involvement confirmed by optical coherence tomography (OCT). The second participant was 14 years old and showed mild non-proliferative diabetic retinopathy, characterized by microaneurysms and dot-and-blot hemorrhages without macular edema.

Among the remaining participants, 111 (96.5%) had normal fundus findings. Two participants (1.7%) showed tilted optic discs with normal retinal findings.

Table 4. Fundus examination findings and prevalence of diabetic retinopathy among children with type 1 diabetes mellitus (n=115)

Finding Category	n %	n	%
Fundus examination	Normal fundus appearance (clear media, normal optic disc, vessels, macula, and peripheral retina)	111	96.5%
Fundus examination	Tilted optic disc with normal macula and peripheral retina	2	1.7%
Fundus examination Diabetic retinopathy	present	2	1.7%
Diabetic retinopathy severity	Mild non-proliferative diabetic retinopathy (NPDR) with microaneurysms and dot-and-blot hemorrhages	1	0.9%
Diabetic retinopathy	severity Moderate NPDR with diabetic macular edema, hemorrhages, and exudates	1	0.9%

Visual acuity was generally preserved among the study participants. In the right eye, 108 participants (93.9%) had a visual acuity of 6/6, while 5 participants (4.3%) had 6/9 vision and one participant each (0.9%) had 6/18 and 6/36 vision. In the left eye, 107 participants (93.0%) had a visual acuity of 6/6, 6 participants (5.2%) had 6/9 vision, and one participant each (0.9%) had 6/18 and 6/36 vision. Most reduced visual acuity cases were related to refractive errors. The right-eye 6/36 finding corresponded to mild NPDR, while the left-eye 6/36 finding corresponded to severe NPDR with DME.

Table 5. visual acuity distribution among children with type 1 diabetes mellitus (n=115)

Visual acuity	Right eye (n)	Right eye findings	Left eye (n)	Left eye findings
6/6	108	Normal vision	107	Normal vision
6/9	5	Myopia (2), corrected to 6/6; Hypermetropia (2), corrected to 6/6; Astigmatism (1), corrected to	6	Myopia (3), corrected to 6/6; Hypermetropia (2), corrected to 6/6; Astigmatism (1), corrected to 6/6
6/18	1	Hypermetropia, corrected to 6/6	1	Hypermetropia, corrected to 6/6
6/36	1	Not corrected Mild NPDR	1	Not corrected Moderate NPDR with diabetic macular edema

The associations between selected demographic and clinical characteristics and the presence of diabetic retinopathy are presented in Table 6. No statistically significant associations were observed between diabetic retinopathy and age group, sex, duration of diabetes, or glycemic control (all $p > 0.05$). However, both participants diagnosed with diabetic retinopathy had a diabetes duration of more than 10 years.

Table 6. association between selected characteristics and diabetic retinopathy among children with type 1 diabetes mellitus (n=115)

Characteristic Category DR	present n (%)	DR absent n (%)	Total n (%)	P value
Age group 10–16 years	0 (0.0%)	75 (100.0%)	75 (65.2%)	0.119
Age group 17–18 years	2 (5.0%)	38 (95.0%)	40 (34.8)	
Gender Male	1 (2.2%)	44 (97.8%)	45 (39.1%)	1.000
Gender Female	1 (1.4%)	69 (98.6%)	70 (60.9%)	
Duration of diabetes ≤5 years	0 (0.0%)	76 (100.0%)	76 (66.1%)	0.534
Duration of diabetes >5 years	2 (5.1%)	37 (94.9%)	39 (33.9%)	
HbA1c level <7%)	0 (0.0%)	13 (100.0%)	13 (11.3%)	1.000
HbA1c level ≥7%	2 (2.0%)	100 (98.0%)	102 (88.7)	

Footnote: P values were calculated using Fishers exact test because of the small number of participants with diabetic retinopathy.

Discussion

The present study assessed the prevalence of diabetic retinopathy (DR) and its associated clinical characteristics among children with type 1 diabetes mellitus attending Kassala Teaching Hospital in eastern Sudan. The overall prevalence of DR was 1.7%, with one participant diagnosed with mild non-proliferative diabetic retinopathy (NPDR) and another with moderate NPDR complicated by diabetic macular edema (DME). Although the prevalence was low, both affected participants had a diabetes duration of more than 10 years, emphasizing the cumulative effect of prolonged hyperglycemia on the development of retinal microvascular complications. The prevalence observed in the present study is lower than that reported in many pediatric populations worldwide, where the prevalence of DR ranges from 2.3% to 57.6%, depending on the study population, duration of diabetes, glycemic control, and

screening strategies [8–10,14,15]. It is also lower than the prevalence reported among children with T1DM in Ethiopia (4.7%) [16]. The relatively low prevalence observed in our study may be explained by the young age of the study population and the relatively short duration of diabetes in most participants, with approximately two-thirds having diabetes for five years or less. Previous studies have consistently shown that the risk of DR increases with longer diabetes duration and remains uncommon during the early years after diagnosis [3,11]. Despite the low prevalence of DR, glycemic control was generally suboptimal in this cohort. Only 11.3% of participants achieved the recommended HbA1c target ($<7\%$), whereas more than half had HbA1c levels $\geq 10\%$, and over 60% reported difficulty maintaining stable blood glucose levels. In addition, approximately half of the participants reported poor adherence to their prescribed treatment regimen. Although no statistically significant association was observed between HbA1c level and DR in the present study, both affected participants had poor glycemic control. The absence of statistical significance is most likely attributable to the very small number of DR cases rather than the absence of a biological association. These findings are consistent with previous evidence identifying chronic hyperglycemia as the most important modifiable risk factor for the development and progression of DR in children and adolescents with T1DM [1,3,4,17].

although the association between diabetes duration and DR did not reach statistical significance, both affected participants had a diabetes duration of more than 10 years. This finding is consistent with the well-established natural history of diabetic retinopathy, in which the risk of retinal microvascular damage increases with prolonged exposure to chronic hyperglycemia. The lack of statistical significance in the present study is most likely attributable to the limited number of DR cases and the relatively small sample size rather than the absence of a true association [3,11]. Similarly, no statistically significant association was observed between age and the presence of DR. Nevertheless, the two participants diagnosed with DR were aged 14 and 18 years, suggesting that retinal complications may become more apparent during adolescence, particularly among patients with long-standing diabetes. This observation is in agreement with previous studies demonstrating that increasing age often reflects longer disease duration and cumulative glycemic exposure rather than acting as an independent risk factor for DR [3,11]. Gender was not significantly associated with diabetic retinopathy, with one case identified in each sex. This finding is consistent with previous reports indicating that sex is not an independent predictor of pediatric diabetic retinopathy [8,10]. Visual function was preserved in the majority of participants, with most eyes demonstrating a best-corrected visual acuity of 6/6. Reduced visual acuity was mainly attributable to refractive errors rather than diabetic retinal disease. Only two participants experienced visual impairment related to mild NPDR in RT eye and the other related to moderate NPDR with diabetic macular edema in LT eye. In this case, optical coherence tomography (OCT) was performed to confirm macular involvement, highlighting the importance of OCT in the evaluation of suspected diabetic macular edema and supporting timely referral and management to prevent irreversible visual loss. A notable finding of this study was the extremely low uptake of diabetic retinopathy screening. Nearly all participants (96.5%) had never undergone a previous dilated fundus examination despite attending regular diabetes follow-up visits. Lack of awareness was the most frequently reported barrier, followed by financial constraints and the absence of visual symptoms. These findings emphasize important

deficiencies in integrating ophthalmic screening into routine pediatric diabetes care and are consistent with reports from other low-resource settings, where limited awareness and restricted access to eye care services remain major barriers to early detection of diabetic retinopathy [10,12,13]. The present study has several strengths. To our knowledge, it is among the first studies to evaluate diabetic retinopathy among children with type 1 diabetes mellitus in eastern Sudan using standardized dilated fundus examination, with OCT performed in suspected cases of macular edema. The study also provides baseline data that may support the development of pediatric diabetic retinopathy screening programs in the region.

Strengths and limitations

To our knowledge, this study provides important baseline data on diabetic retinopathy among children with T1DM attending a diabetic clinic in eastern Sudan. The study included systematic dilated fundus examination, with independent confirmation of retinal findings by a senior ophthalmologist and OCT assessment when DME was clinically suspected.

However, several limitations should be acknowledged. First, the hospital-based cross-sectional design and single-center setting limit the generalizability of the findings to the wider pediatric diabetic population in Sudan. Second, the relatively small sample size and, particularly, the very small number of DR cases substantially limited the statistical power to detect associations between potential risk factors and DR. Therefore, the absence of statistically significant associations should not be interpreted as evidence that these factors are unrelated to DR. Third, the cross-sectional design does not allow assessment of temporal or causal relationships between glycemic control, diabetes duration, and DR. Fourth, retinal assessment was primarily based on clinical fundus examination rather than standardized digital fundus photography, which may have reduced sensitivity for subtle early retinal lesions. OCT was performed when DME was clinically suspected rather than routinely in all participants. Finally, some clinical and laboratory information was obtained from medical records when available, and missing information may have affected the completeness of some analyses.

Conclusion

This study found a low prevalence of diabetic retinopathy (1.7%) among children with type 1 diabetes mellitus attending Kassala Teaching Hospital. However, the presence of mild and moderate non-proliferative diabetic retinopathy, including one case with diabetic macular edema, indicates that retinal complications can occur during childhood, particularly in patients with long-standing diabetes. The extremely low uptake of retinal screening and the high frequency of poor glycemic control highlight the need to integrate routine ophthalmic screening into pediatric diabetes care. Early detection, improved glycemic control, and increased awareness are essential to reduce the future burden of diabetes-related visual impairment.

Recommendations Strengthen routine retinal screening for children/adolescents according to applicable pediatric diabetes screening guidelines. Strengthen glycemic control and routine HbA1c monitoring. Establish clear referral pathways between diabetic and ophthalmology clinics. Increase awareness/education among families and healthcare providers. Larger multicenter prospective studies using standardized retinal imaging and longitudinal follow-up are needed to better characterize the burden, progression, and risk factors of diabetic retinopathy among children and adolescents with diabetes in Sudan

Abbreviations

BMI; Body Mass Index, **DM**; Diabetes Mellitus, **DR**; Diabetic Retinopathy, **ETDRS**; Early Treatment Diabetic Retinopathy Study, **HbA1c**; Glycated Hemoglobin, **NPDR**; Non-Proliferative Diabetic Retinopathy, **T1DM**; Type 1 Diabetes Mellitus, **T2DM**; Type 2 Diabetes Mellitus.

Declarations

Ethics approval and consent to participate

Ethical approval was obtained from the relevant Ethics Review Committee prior to commencement of the study. Written informed consent was obtained from parents or legal guardians of all participants, and assent was obtained from children before enrollment. The study was conducted in accordance with the Declaration of Helsinki. All collected data were handled confidentially and anonymized to protect participants' privacy.

Consent for publication

Not applicable. No identifiable images or personal information of participants are included in this manuscript.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

FAMS and HAMA wrote the main manuscript. SAKA and WAAM critically revised the manuscript. All authors reviewed and approved the final version of manuscript..

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Use of artificial intelligence-assisted tools

Artificial intelligence-assisted tools were used only to support language editing and manuscript formatting. The authors reviewed and verified all content and take full responsibility for the accuracy, interpretation, and conclusions presented in this manuscript.

Data Availability and materials

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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