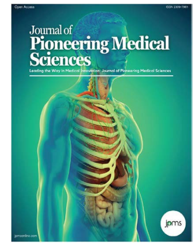

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Parental Perceptions of Robot-Assisted Diabetes Education for Children with Type 1 Diabetes in Saudi Arabia: A Cross-Sectional Study

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Abstract **Objective:** This study aimed to explore parental perceptions of robot-assisted diabetes education delivered through the Pepper humanoid robot among children with T1DM. **Methods**: A descriptive cross-sectional study was conducted using a validated questionnaire based on the Technology Acceptance Model and Theory of Planned Behavior for parents whose children participated in a robot-assisted diabetes education program. Parents' perceptions were measured across domains of perceived usefulness, trust and safety, engagement, satisfaction and behavioral intention. Both Likert-scale items and open-ended questions were included. **Results**: Parental perceptions were highly positive. The highest scores were observed for perceived usefulness (mean = 4.44±0.47) and child engagement (mean = 4.28±0.58). Trust and safety were also rated favorably. Parents with greater technological familiarity reported higher satisfaction scores ($p<0.05$). Significant negative correlations were found between HbA1c and perceived usefulness ($\rho = -0.52$, $p = 0.024$) and trust and safety ($\rho = -0.48$, $p = 0.039$). Open-ended responses emphasized the robot's role in simplifying complex information, sustaining children's attention and promoting independence, while also recommending improvements in technical performance and cultural adaptation. **Conclusion**: Parents viewed SARs as valuable, safe and engaging tools for pediatric diabetes education. Their integration into clinical care holds promise for enhancing engagement and self-management in children with T1DM, provided that issues of cultural relevance and digital literacy are carefully addressed.

Key Words Socially Assistive Robots, Type 1 Diabetes Mellitus, Pediatric Diabetes Education, Parental Perceptions, Technology Acceptance Model, Pepper Humanoid Robot

INTRODUCTION

Advances in diabetes technologies, including insulin pumps and continuous glucose monitoring systems, have improved clinical outcomes in children and adolescents with type 1 diabetes mellitus (T1DM) [1]. However, access to these technologies remains inconsistent, with global surveys indicating that coverage and reimbursement policies largely determine availability, particularly in low- and middle-income regions [2].

Technology-based tools, such as mobile applications, web-based platforms and socially assistive robots (SARs) have emerged as promising solutions to support diabetes self-management across diverse healthcare settings. A systematic review found that technology-based interventions improved glucose monitoring, insulin administration and dietary adherence, particularly when designed to be interactive and developmentally appropriate for children [3]. In Saudi Arabia, the prevalence of T1DM in children has grown significantly in recent years, necessitating innovative educational approaches. Digital health solutions, including SARs, are increasingly recognized for their potential to enhance engagement and learning. A randomized controlled trial demonstrated that SAR-based education significantly improved diabetes knowledge and glycemic outcomes in Saudi children with T1DM [4]. Research on educational technology adoption further indicates that parental acceptance, child engagement and trust in technology are key factors for successful implementation [5-7].

SARs are designed to deliver interactive instruction through verbal communication, gestures, touchscreen displays and gamified learning elements. Prior studies have shown that children respond positively to robot-assisted education, demonstrating improved motivation, concentration and knowledge retention [8,9]. A study revealed that a personal robot could personalize diabetes education based on individual learning needs [10]. In addition to enhancing education, improving psychosocial outcomes and quality of life is a core goal of pediatric diabetes care. Younger children, particularly preschoolers, face unique challenges in managing diabetes-related distress and treatment burdens [11]. Emotionally engaging, parent-inclusive educational methods may help mitigate these burdens and promote better long-term disease management.

Despite promising evidence, parental perspectives on the safety, usefulness and cultural acceptability of robot-assisted diabetes education remain underexplored. Most existing studies have focused on children's learning outcomes or technological feasibility, with limited attention to how parents perceive, trust and accept these tools. However, most existing research has focused on children's engagement, learning outcomes and the technical feasibility of SARs, with limited exploration of how parents perceive and accept these technologies. Studies seldom address parental trust, perceived safety and cultural fit factors that critically determine the success of educational innovations in family-centered diabetes care [12,13]. Understanding parental perspectives is critical, as parents serve as primary decision-makers and facilitators of diabetes care in early childhood. Their acceptance directly influences children's engagement, adherence and sustained use of such innovations in real-world settings [14].

Objectives

This study aimed to explore parental perceptions of SAR–based diabetes education among children with T1DM in Saudi Arabia. Specifically, it examined perceptions across the domains of perceived usefulness, child engagement, trust and safety, satisfaction and behavioral intention.

METHODS

Study Design and Setting

This cross-sectional, descriptive survey study assessed parental perceptions of using SARs, specifically the Pepper robot, for diabetes education in Saudi children with T1DM. The study was a follow-up to a previously published randomized controlled trial (RCT), which demonstrated that robot-assisted education significantly improved children's diabetes knowledge and metabolic control compared with conventional nurse-led education [4]. The present study was conducted at the Pediatric Diabetes Clinic of the University of Tabuk Medical Center, the same site as the original RCT.

Participants and Sampling

Eligible participants were parents or primary caregivers of children aged 5–15 years who had been assigned to the robot-assisted education group in the prior trial. A convenience sampling approach was used to recruit parents who were available during clinic visits or reachable via contact information from the prior RCT database. Inclusion criteria required parents to provide informed consent and demonstrate the ability to complete a structured questionnaire in either Arabic or English. Parents of children who had received traditional nurse-led education or who provided incomplete or duplicate responses were excluded.

Figure 1: Parent and Child attending the educational session with the Social Robot

Participants were recruited during routine clinic visits or contacted via phone/email using information collected during the prior trial. Of 19 eligible parents, all agreed to participate, yielding a 100% response rate. Written informed consent was obtained before enrollment. Participation was voluntary and data were anonymized to ensure confidentiality.

Demographic data collected included parent age, education level, occupation and familiarity with technology. Child-specific clinical information included age, duration of diabetes, most recent glycated hemoglobin (HbA1c) level and insulin regimen type, either multiple daily injections (MDI) or insulin pump. Figure 1 shows a parent and child attending a robot-assisted education session.

Data Collection Tools

A structured, self-administered questionnaire was developed to evaluate parental perceptions of robot-assisted diabetes education. Guided by the integrated Technology Acceptance Model (TAM) and Theory of Planned Behavior (TPB) frameworks [9] and prior evidence of SAR use in pediatric diabetes education [10], the questionnaire assessed six domains:

- Perceived Usefulness: Belief that the robot enhanced the child's understanding of diabetes management
- Attitude Toward Robot Use: Overall parental acceptance and openness toward robotic interventions
- Engagement: Perceived attentiveness and interaction of the child during sessions
- Trust and Safety: Parental comfort and safety perception regarding child-robot interaction
- Satisfaction and Preference: General satisfaction with the robot-assisted approach compared with traditional education

- Behavioral Intention: Willingness to continue or recommend robot-assisted education in the future

Each domain included multiple items rated on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). Open-ended questions were included to capture qualitative insights, asking parents to describe (1) aspects they liked most, (2) concerns or reservations and (3) suggestions for improving robot-assisted education.

Content validity was established through expert review by pediatric endocrinologists, a pediatrician, certified diabetes educators and a researcher in human–robot interaction, feedback-informed refinement of wording, removal of redundancies and cultural adaptation. Internal consistency reliability was evaluated using Cronbach's alpha, which demonstrated acceptable reliability across all domains ($\alpha = 0.82$). Face validity was assessed through a pilot test with five parents who met the inclusion criteria. Minor adjustments were made to improve clarity and flow.

The educational intervention used the Pepper humanoid robot, as detailed in the original RCT [4]. The robot delivered structured self-management education in spoken Arabic, with animated gestures and an integrated touchscreen, as shown in Figure 1. Modules included insulin administration, glucose monitoring and dietary practices. The content was tailored to children's developmental levels and delivered interactively to improve engagement. Technical specifications and deployment procedures are described in detail in the prior RCT publication. Data was collected on paper during clinic visits or via a secure online platform (Google Forms) for over 6 weeks. All responses were anonymous and data were stored on a password-protected computer accessible only to the research team to ensure confidentiality and data security.

Data Analysis

Quantitative data were analyzed using SPSS version 22.0. Descriptive statistics (means, standard deviations, medians, frequencies) summarize parental perception scores. Non-parametric tests, including the Mann–Whitney U and Kruskal–Wallis tests, were used to examine subgroup differences based on demographic and clinical characteristics. Spearman's rank correlation was used to assess relationships between HbA1c and perception domains. Data normality was evaluated using the Shapiro–Wilk test, which indicated non-normality; therefore, non-parametric tests were applied. Effect sizes and 95% confidence intervals were calculated where applicable to support the interpretation of statistical significance. A p-value<0.05 was considered statistically significant.

Qualitative responses were analyzed using thematic content analysis. To enhance reliability, two independent researchers coded the data and discussed discrepancies until consensus was reached. Disagreements were resolved through discussion, ensuring consistency in theme interpretation.

Ethics Approval

Approved by the Ethics Committee of the University of Tabuk (Approval No. UT-316-156-2023). The study adhered to the Declaration of Helsinki. Written informed consent was obtained from all participants.

RESULTS

A total of 19 parents was eligible for inclusion based on their children's prior assignment to the robot-assisted education group in the original randomized controlled trial. All 19 were successfully contacted, consented to participate and completed the questionnaire. No participants were excluded after enrollment. There were no cases of non-participation among eligible individuals; all parents approached agreed to take part. Demographic and clinical characteristics are summarized in Table 1. Key features included parental age, education level, technological familiarity and children's clinical characteristics, including insulin regimens and disease duration. Subgroup analyses were performed to examine associations between parental education level and perception domains (Satisfaction, Trust and Perceived Usefulness). Spearman's rank correlation was used to assess relationships between children's HbA1c levels and parental perceptions across all six domains. No formal sensitivity analyses were conducted, as the dataset had no missing values and all eligible participants were included in the study. Parents were predominantly well-educated, middle-aged and technologically literate. Most children used multiple daily injection therapy and had suboptimal glycemic control, reflecting a realistic clinical cohort.

Parental perceptions across all evaluated domains were positive, with mean scores consistently above 3.9 on a 5-point Likert scale (Table 2). The highest-rated domain was perceived usefulness, followed by engagement and motivation. Attitudes toward robot use and behavioral intention for future use reflected strong parental support for continued and broader implementation of robot-assisted education. Slightly lower yet favorable ratings were observed for satisfaction and preference and trust and safety, suggesting minor variability in comfort or trust levels.

Table 1: Participant Demographic Characteristics (N = 19)

Variable	Category	n (%)
Parent age	Mean±SD	40.8±5.1
Father's education	Illiterate	1 (5.3%)
	Less than high school	1 (5.3%)
	High school graduate	4 (21.1%)
	Bachelor's degree or higher	13 (68.4%)
Mother's education	Illiterate	1 (5.3%)
	Less than high school	3 (15.8%)
	High school graduate	3 (15.8%)
	Bachelor's degree or higher	12 (63.2%)
Parent's tech familiarity	Poor	1 (5.3%)
	Fair	3 (15.8%)
	Excellent	15 (78.9%)
Disease duration	Less than 1 year	3 (15.8%)
	1 to 3 years	7 (36.8%)
	3 to 5 years	8 (42.1%)
	More than 5 years	1 (5.3%)
Insulin regimen	Multiple daily injections (MDI)	17 (89.5%)
	Two daily injections	1 (5.3%)
	Insulin pump	1 (5.3%)
Latest HbA1c	7.0 to 7.5%	8 (42.1%)
	8.5 to 10%	4 (21.1%)
	More than 10%	7 (36.8%)

SD: Standard deviation; HbA1c: Glycated hemoglobin, MDI: Multiple daily injections

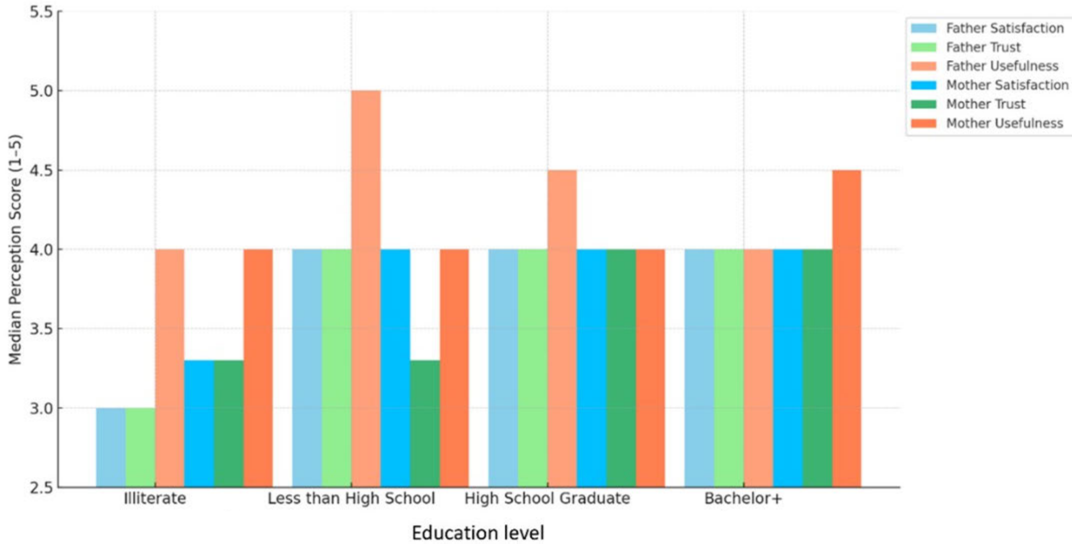

Figure 2: Parental Perception Scores by Education Level

Table 2: Mean parental perception scores across six evaluated domains of robot-assisted diabetes education

Perception Domain	Mean	Standard Deviation (SD)
Perceived Usefulness	4.44	0.47
Attitudes Toward the Use of Robots	4.30	0.46
Trust and Safety Perceptions	3.93	0.31
Cultural and Religious Acceptability	4.05	0.23
Satisfaction and Preference	3.95	0.40
Behavioral Intention for Future Use	4.14	0.52
Perceived Ease of Use	4.25	0.54
Child Engagement and Motivation	4.28	0.58

Note: Ratings were based on a 5-point Likert scale, where higher scores reflect more favorable perceptions.

Table 3: Correlations between parental perception domains and children's HbA1c levels.

Perception Domain	Spearman's ρ	p-value
Perceived Usefulness	-0.52	0.024
Attitude Toward Robot Use	-0.39	0.102
Trust and Safety	-0.48	0.039
Cultural/Religious Acceptability	-0.24	0.325
Satisfaction and Preference	-0.36	0.126
Behavioral Intention	-0.41	0.085

Table 4: Parental Positive Feedback on Robot-Assisted Education Sessions

Theme	No. of Mentions (n)	Percentage	Example Quote
Child Engagement	12	57.1%	"My child was very focused and happy to learn."
Improved Understanding	9	42.9%	"It made complex topics easier for my child."
Innovation & Novelty	7	33.3%	"The sessions were like a game for the child."
Visual/Auditory Appeal	5	23.8%	"The colorful animations made learning more fun."

Parental education level (both paternal and maternal) was analyzed in relation to perceptions of robot-assisted education across three key domains: Satisfaction, Trust and Perceived Usefulness. Parents with higher educational attainment reported equal or higher perception scores, particularly in the Usefulness domain. Trust scores among mothers were more variable, with lower ratings in the "Less than High School" group. Illiterate parents, both fathers and mothers, consistently reported lower scores in Satisfaction and Trust, emphasizing the need for additional support and tailored communication strategies for families with limited education, as Figure 2 demonstrated. Glycemic control, assessed by the most recent HbA1c values, was correlated with parental perceptions across six composite domains using Spearman's rank correlation coefficients (ρ) (Table 3).

A moderate, statistically significant negative correlation was observed between HbA1c and perceived usefulness ($\rho = -0.52$, $p = 0.024$), indicating parents of children with better glycemic control perceived robot-assisted education as more beneficial. A significant negative correlation was also found with trust and safety ($\rho = -0.48$, $p = 0.039$). Clinically, this suggests that positive parental engagement and belief in SARs may translate into improved adherence behaviors and better glycemic outcomes in children. Other domains demonstrated non-significant trends; however, the overall pattern suggested that lower HbA1c levels were generally associated with higher parental satisfaction.

Qualitative findings complemented the quantitative results. Parents provided open-ended feedback on their experiences (Table 4), highlighting several positive aspects of robot-assisted education. The most frequently cited advantage was child engagement (57.1%), noting the robot's ability to capture attention through interactive and visually stimulating features. Additionally, 42.9% reported that the robot simplified complex diabetes concepts, aiding comprehension. One-third of respondents (33.3%) valued the novelty and innovation of using a robot as a teaching tool, which contributed to motivation and interest. A smaller proportion (23.8%) appreciated visual and auditory elements (animations, voice) that enhanced learning.

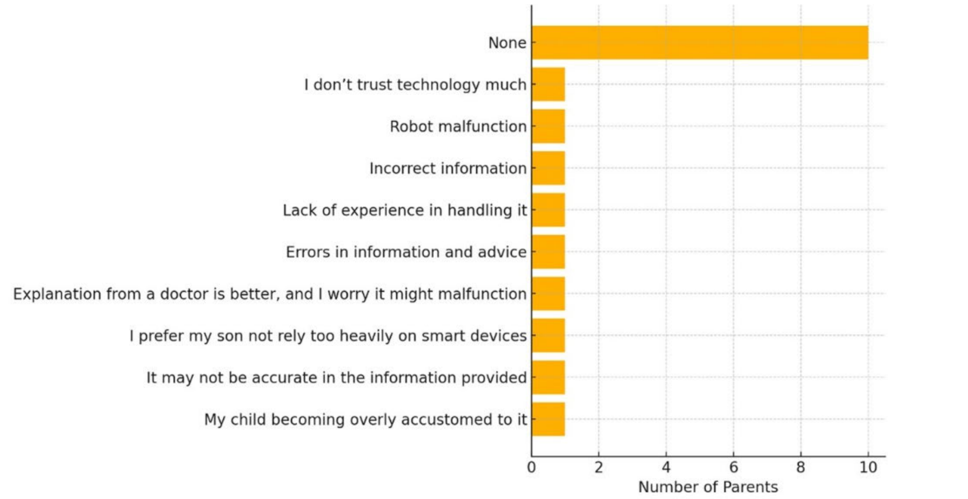

Figure 3: Parents concern about using Robot in education

Most parents reported no concerns, indicating general trust and acceptance of robot-assisted education. However, some expressed reservations, including over-reliance on technology (e.g., children preferring robotic over human explanations), doubts about accuracy and reliability (e.g., potential misinformation or malfunction) and low personal trust in technology due to limited experience. These findings suggest that while overall parental receptivity is high, addressing technological reliability, providing clear guidance and enhancing caregivers' digital confidence may further improve acceptance, as shown in Figure 3.

Parents also offered suggestions to enhance robot-assisted education. Common themes included requests for longer, more interactive sessions, better integration with human educators and clearer, more personalized educational content. While many suggestions were unique, they collectively reflect strong engagement and an interest in refining the approach to maximize educational effectiveness.

DISCUSSION

This study indicates that SARs are a feasible and well-accepted tool for enhancing diabetes education among children with T1DM. Parental responses reflected strong engagement and satisfaction, suggesting that interactive, child-centered technologies can foster more effective learning and family involvement in diabetes management. The observed association between higher parental education, better glycemic control and more favorable perceptions suggests that technological literacy and health outcomes may reinforce one another**.** Consistent with the study objectives, parents reported high levels of perceived usefulness, engagement and satisfaction, with generally positive attitudes toward the use of SARs. Higher educational attainment and better glycemic control were associated with more favorable perceptions and qualitative feedback underscored the value of interactive, visually engaging content.

Our findings complement results from the preceding randomized controlled trial [4], which demonstrated that robot-assisted sessions improved children's knowledge and metabolic control compared with conventional nurse-led education. This follow-up study adds psychosocial and behavioral insights, showing that parents value SARs as an effective adjunct to traditional education in pediatric diabetes management. To our knowledge, this is the first study in the Middle East and specifically in Saudi Arabia to explore parental perceptions of SARs in pediatric diabetes education.

Our findings further support theoretical frameworks such as TAM and TPB, which posit that perceived usefulness and ease of use are strong predictors of technology adoption [12,13]. The TPB, one of the most widely applied social cognitive theories, predicts behavioral intentions and health-related behaviors [14,15]. It has been successfully applied to domains such as myopia prevention and parental decisions about childhood vaccination [16,17].

Several studies have extended these models to various digital contexts, including the integration of TAM and TPB with risk perception to predict telecommuting behavior during the COVID-19 pandemic [18], the use of social networking applications in Egyptian higher education [19], remote learning experiences in vocational settings [20] and Zoom adoption among Cambodian students to support online learning [21].

TAM is among the most widely used models for studying user acceptance of technology and includes five primary constructs: Perceived Usefulness, Perceived Ease of Use, Attitude Toward Use, Behavioral Intention and Actual Use [22,23].

Parents in this study rated domains such as perceived usefulness, trust and behavioral intention highly, reinforcing the potential of SARs to enhance diabetes education. Prior literature suggests that robots can act as engaging, motivating mediators in pediatric care and developmental rehabilitation [24,25]. Significantly, parental familiarity with technology was associated with more favorable perceptions, consistent with prior research showing that technologically literate parents are more likely to engage positively with AI-driven tools [26].

Qualitative comments indicated appreciation for the robot's ability to simplify complex information, promote independence and sustain attention. However, concerns about technical reliability and the emotional adaptability of robots mirrored findings from previous studies, which noted ambivalence around robots expressing emotion or appearing too human-like [13].

The results support integrating SARs into clinical pediatric diabetes education, particularly in regions that embrace digital health strategies. High parental satisfaction suggests the potential for broader adoption across clinical settings [8]. In addition to enhancing engagement and comprehension, SARs may complement provider-led instruction and support family-centered care models [27]. Orientation sessions may also be necessary to bridge comfort gaps, especially among caregivers unfamiliar with robotic platforms [28].

Differences in perception scores by parental education level underscore the importance of tailoring implementation strategies. Educational content should incorporate simple language, visual aids and caregiver-focused modules to maximize accessibility and inclusivity, particularly in populations with lower literacy levels. As AI tools become more prevalent in healthcare, this study affirms that SARs are not only acceptable to families but also valued when thoughtfully deployed.

This study has several strengths. It is one of the first detailed examinations of parental perceptions of robot-assisted diabetes education for children, offering a novel, region-specific contribution from Saudi Arabia. It complements prior randomized controlled research by incorporating psychosocial and behavioral insights that extend understanding beyond clinical outcomes. The use of validated theoretical frameworks, the Technology Acceptance Model (TAM) and the Theory of Planned Behavior (TPB), enhances conceptual rigor, while combining quantitative and qualitative methods enriches data interpretation. Full participation of all eligible parents further strengthens the study's internal validity and ensures that the findings represent the complete target population.

However, certain limitations should be acknowledged. The study's single-center design and modest sample size may limit the generalizability of its findings, potentially failing to reflect parental perspectives across diverse cultural or socioeconomic contexts. Self-reported data could have introduced social desirability bias, as some participants may have provided overly favorable responses. In addition, the cross-sectional design captures perceptions at a single time point, preventing the evaluation of long-term parental and child outcomes. Future research should involve larger, multicenter cohorts with diverse backgrounds, employ longitudinal designs and include economic evaluations to assess the sustainability and cost-effectiveness of robot-assisted diabetes education.

CONCLUSIONS

Parental perceptions of robot-assisted diabetes education were positive, supporting the feasibility of incorporating SARs into pediatric diabetes care. Larger multicenter studies with longer follow-up are needed to validate these findings and assess their impact on glycemic control. Ensuring cultural relevance and promoting digital literacy will be crucial to successful, equitable adoption in real-world clinical settings.

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The author acknowledges the research team from the previously published RCT, "Improving Diabetes Education and Metabolic Control in Children Using Social Robots," which served as the foundation for this follow-up study. This study was independently designed, executed and reported by the author.

Ethical Statement

Written informed consent was obtained from the parent and child in Figure 1 for the publication in this article. The parent was fully informed about the purpose of capturing the image, its use in an Elsevier publication (both in print and online) and the potential for the image to be discoverable through search engines and once published, the image cannot be withdrawn. Identifying features were minimized in the final image to further ensure privacy, without compromising the scientific value of the visual content. This consent process adhered to all relevant Data Protection and Privacy Laws, including the GDPR and HIPAA.

Declaration of Generative Artificial Intelligence in Scientific Writing

During the preparation of this work, the author used ChatGPT (OpenAI, San Francisco, CA) to assist with language refinement, paraphrasing and figure formatting. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the publication's content.

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