RESEARCH PAPER

The Regulatory Pathways And Safety Profiles Of Software As Medical Devices For Diabetes And Obesity In Metabolic Disease Management

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Abstract

Objective Adaptive Software as Medical Devices (SaMDs) are revolutionizing the management of metabolic diseases like diabetes and obesity through real-time analytics and AI-driven clinical support. However, rapidly evolving regulations pose challenges for clinics, patient safety, and innovation. As the global impact of diabetes and obesity grows, there is a notable gap in understanding regulatory pathways, clinical trial rigor, and post-market safety for adaptive SaMDs. This research analyzes the clearance processes, clinical evidence's quality, and SaMDs' safety profiles designed for diabetes and obesity management, focusing on insulin dosing algorithms and continuous glucose monitoring. **Methods** A review of FDA and EMA databases from January 2004 to December 2024, emphasizing US FDA approvals, we identified 23 SaMDs that met our criteria. **Results** Our findings revealed, nearly all SaMDs cleared through 510(k) pathways, primarily classified as Class II devices (96%). Approval times typically ranged from 12-18 months, with adaptations requiring an additional 6-12 months. While clinical trials were multicenter and focused on adults aged between 18 to 64 years, and there was limited representation of pediatric populations. **Conclusion** Key safety concerns included severe hypoglycaemia (2 to 5 episodes per 100 patient years) and device malfunctions, which led to recalls. Moving forward, addressing regulatory differences, enhancing pediatric studies, and reinforcing cybersecurity measures will be essential. Robust post-market surveillance and aligned global regulations are crucial for ensuring safe and equitable access to these innovative tools. Future research should delve into long-term outcomes and real-world effectiveness to unlock the full potential of adaptive SaMDs.

Keywords Software as Medical Device, Diabetes management, Obesity, FDA 510(k) clearance, Adaptive algorithms, Continuous glucose monitoring

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Introduction

Metabolic diseases, including diabetes and obesity, are major challenges for global health systems. It's projected that by 2025, there will be around 643 million cases of diabetes and over a billion adults affected by obesity [1, 2]. Current management approaches, which often consist of clinical visits, manual tracking, and fixed treatment plans, that do not adequately address these chronic conditions. However, recent advancements in artificial intelligence and continuous monitoring have led to the development of adaptive Software as Medical Devices (SaMDs) that allow for timely treatment adjustments. Artificial intelligence and machine learning are transforming multiple areas of medicine, including drug development and medical device innovation [3], with regulatory frameworks evolving to accommodate these technologies.

Regulatory bodies like the FDA, EMA, and PMDA have streamlined approval processes for these devices, striving for a balance between innovation and safety. There's a common relationship between diabetes and obesity, with 80-90% of type 2 diabetes patients being overweight or obese. Previous studies suggests that, achieving a weight loss of just 5-10% can significantly improve blood sugar control [4]. This research focus on SaMDs that support patients with metabolic syndrome, particularly emphasizing on the connection between glucose control and weight management.

Despite growing importance of SaMDs, there is a no proper pathways for a comprehensive review examining their regulatory pathways, clinical trial results, and safety profiles. Most existing studies focused on specific devices, but not focused on important comparisons between adaptive systems that utilize machine learning and fixed-protocol tools [5, 6]. Additionally, major

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limitations remain in areas such as paediatric device development, manufacturer distribution, reapproval timelines, recall histories, and cybersecurity.

This research aims to address these limitations by analysing 23 FDA-cleared SaMDs for diabetes and obesity management from January 2004 to December 2024. The objectives are to: (1) detail approval timelines for adaptive versus non-adaptive devices, (2) analyse the designs of clinical trials, (3) assess post-market safety, (4) investigate pediatric device development, and (5) compile cybersecurity protocols. The findings from this study are important for various stakeholders, providing insights to regulators, clinicians, manufacturers, and policymakers. The 23 identified SaMDs were located through FDA databases and clinical trial registries and categorized as adaptive or non-adaptive, which will inform subsequent analyses on regulatory and safety aspects**.**

Methods and Materials

Study Design

This research includes regulatory routes, clinical evidence, and safety profiles of Software as Medical Devices (SaMDs) for managing diabetes and obesity from January 2004 to December 2024. This study design combined quantitative analysis of regulatory timelines, clinical trial characteristics, and adverse events with qualitative synthesis of cybersecurity protocols and workflow integration strategies.

Data Sources and Search Strategy

Systematic searches were conducted across FDA 510(k) and De Novo databases [7] (U.S. Food and Drug Administration, 2024), FDA MAUDE database [8] (U.S. Food and Drug Administration, 2025), EMA regulatory updates [9] (European Medicines Agency, 2025), PMDA announcements [10] (Pharmaceuticals and Medical Devices Agency, 2024), IMDRF guidance documents [11] (International Medical Device Regulators Forum, 2023), ClinicalTrials.gov [12] (ClinicalTrials.gov, 2025), and manufacturer regulatory submissions. Search terms included: “insulin dosing,” “glucose monitoring,” “diabetes management,” “adaptive algorithm,” “SaMD,” “digital therapeutic” and “Frequently modifying SaMD”. Searches conducted in June 2025 covered devices approved from January 2004- December 2024. Initial searches identified 1012 devices, after removing duplicates and applying eligibility screening, 23 SaMDs meeting final inclusion criteria.

Eligibility Criteria

Inclusion criteria was FDA clearance (January 2004–December 2024), explicit functionality in insulin dosing/glucose monitoring/behavioral guidance, complete regulatory documentation, English-language materials, current or documented market history. The exclusion criteria includes Investigational devices without clearance, non-FDA approvals only, hardware-only devices, market withdrawal before 2020, and insufficient documentation.

Device Categorization

Devices were classified as adaptive (algorithmic modification based on patient data) or non-adaptive (static protocols requiring manual adjustment) based on FDA AI/ML-based SaMD guidance [13] and IMDRF frameworks [11]. Classification were done accordingly using regulatory documentation and the definitions provided by IMDRF, USFDA, EMA. Final categorization was given in Table 1.

Table 1: **Regulatory Status, Approval Dates, and Descriptions of Selected Diabetes and Metabolic Care SaMDs**

S. No	SaMD	Category	FDA Status	510(k)/De-Novo No.	Health Authority Approval Date	One-line Description
1	Omnipod 5 Automated Insulin Delivery System	Adaptive	510(k) Cleared	K203774	Jan 28, 2022	Tubeless, automated insulin pump that adjusts dosing in real time using CGM data.
2	CamAPS FX	Adaptive	510(k) Cleared	K232603	Dec 18, 2023	Hybrid closed-loop system using CGM to automatically adjust insulin with learning algorithms.
3	Control-IQ Technology	Adaptive	510(k) Cleared	K232382	Dec 6, 2023	Automated insulin dosing algorithm for pumps using real-time CGM to maintain glucose within target range.
4	d-Nav System	Adaptive	510(k) Cleared	K181916	Sept 23, 2019	Adaptive insulin dosing tool that frequently recalibrates dosing recommendations based on live data.

5	WellDoc BlueStar	Adaptive	510(k) Cleared	K230813	Sept 5, 2023	Digital therapeutic for type 2 diabetes offering personalized, data-driven feedback and guidance.
6	Clarian Glucose Stabilizer	Non-Adaptive	510(k) Cleared	K071713	Jul 9, 2007	Insulin dosing calculator applying fixed protocols (non-adaptive) for therapy recommendations.
7	EndoTool IV 1.10	Non-Adaptive	510(k) Cleared	K200443	Feb 28, 2020	IV insulin dosing tool based on predetermined protocols and algorithms.
8	EndoTool SubQ 2.1	Non-Adaptive	510(k) Cleared	K211160	Jul 15, 2021	Subcutaneous insulin dosing software using fixed, protocol-based calculations.
9	Freestyle Auto-Assist v2.0	Non-Adaptive	510(k) Cleared	K123089	Aug 22, 2012	Software assisting insulin dosing with preset rules derived from CGM data.
10	GLUCOFACTS EXPRESS	Non-Adaptive	510(k) Cleared	K082486	Sept 23, 2008	Digital platform offering diabetes management and dosing advice via fixed algorithms.
11	GLUCOMMANDER PLUS	Non-Adaptive	510(k) Cleared	K061110	Sept 25, 2006	Protocol-driven decision support tool for insulin dosing using static guidelines.
12	Go Dose System	Non-Adaptive	510(k) Cleared	K160949	Nov 17, 2016	Insulin dosing calculator using fixed pharmacokinetic and clinical models.
13	Health-e-Connect System	Non-Adaptive	510(k) Cleared	K102063	Nov 9, 2010	Data management/communication platform aggregating diabetes data with preset processing rules.
14	InPen Dose Calculator	Non-Adaptive	510(k) Cleared	K242775	Jan 30, 2024	Smart insulin pen aid, suggesting doses using fixed algorithms.
15	Insulia Bolus Companion	Non-Adaptive	510(k) Cleared	K232451	Dec 11, 2023	Mobile insulin dosing app delivering fixed-protocol advice and educational resources.
16	My Insulin Doser (IDS)	Non-Adaptive	510(k) Cleared	K082512	Oct 9, 2008	Calculator tool providing static, guideline-based insulin dosing recommendations.
17	KidneyIntelX.dkd	Non-Adaptive	De Novo Authorized	DEN200052	Dec 2, 2020	Risk stratification tool for diabetic kidney disease monitoring via established static parameters.
18	My Dose Coach	Non-Adaptive	510(k) Cleared	K163099	June 16, 2017	Dosing aid for insulin delivery using standardized, fixed algorithms for diabetes management.
19	OneTouch Zoom Program	Non-Adaptive	510(k) Cleared	K081318	Sept 25, 2008	Diabetes data management/decision-support platform with preset rule-based logic.
20	PILL PHONE	Non-Adaptive	510(k) Cleared	K060298	May 4, 2006	Medication adherence and tracking tool using

						predetermined reminders and protocols.
21	Precision Link Diabetes System	Non-Adaptive	510(k) Cleared	K040628	Mar 18, 2004	Data aggregation tool for diabetes, enabling clinician decisions on a fixed protocol basis.
22	SmartBolus Calculator	Non-Adaptive	510(k) Cleared	K231824	Nov 17, 2023	Portable insulin bolus calculator using validated fixed algorithms.
23	Sparse Sample PK Profile (myPKFiT)	Non-Adaptive	510(k) Cleared	BK170028	Jul 18, 2018	Pharmacokinetic model-based dosing software for insulin therapy recommendations.

Data Extraction

Standardized extraction included were device name, manufacturer location, clearance pathway/number, approval date, classification (Class II/III), OTC/Rx status, panel, primary product code, and clinical speciality under regulatory criteria. In the clinical trials component, design type, sites, sample demographics, control groups, endpoints, and precision metrics were included for this study. The safety criteria includes, MAUDE recall events, adverse reactions, and device malfunctions. The technical aspects consists of, adaptive/non-adaptive status, CGM integration, cybersecurity documentation, human factors validation, pediatric indications. Finally timelines include reapproval durations post-adaptation.

Data Analysis

Quantitative Analysis: Descriptive statistics showed how devices are distributed across regulatory pathways, classifications, manufacturers, and geographic locations. For continuous variables like approval timelines, reapproval durations, and sample sizes, we calculated median values and ranges. We presented categorical variables, such as adaptive vs. non-adaptive functionalities, trial design types, and age groups, using frequencies and percentages.

Devices were divided by (1) adaptive vs. non-adaptive functionality, (2) FDA risk classification (Class II vs. Class III), (3) regulatory pathway (510(k) vs. De Novo), and (4) clinical specialty. We compared differences in approval timelines, clinical trial characteristics, and recall patterns across these groups. We assessed safety data from the MAUDE database for recall frequency, causes, severity and categorized the counted types of adverse events where adequate data were available. For devices that reported precision metrics, such as CGM accuracy, are extracted and summarized the performance data.

Qualitative Synthesis: We clubbed regulatory frameworks, cybersecurity protocols, human factors, and clinical workflow integration strategies thematically. By thorough review of regulatory and commercial documents, we noticed different patterns in pediatric device development, manufacturer clustering, and third-party platform integration.

Data Visualization: We used Microsoft Excel to create bar charts, box plots, and geographic distribution maps to visualize the results. We conducted all data extraction, analysis, and synthesis between August and October 2025**.**

Results

Device Characteristics and Selection

Device Selection and Categorization

The study included Twenty-three Software as Medical Devices (SaMDs) for diabetes and obesity management that met inclusion criteria (Table 1). Devices were categorized as adaptive (n=5, 22%) or non-adaptive (n=18, 78%) based on algorithmic functionality. Adaptive devices are Omnipod 5 Automated Insulin Delivery System, CamAPS FX, Control-IQ Technology, d-Nav System, and WellDoc BlueStar that incorporated real-time algorithmic modification capabilities. Non-adaptive devices were included based on predetermined, static clinical protocols requiring manual parameter adjustments.

Manufacturer Distribution and Geographic Clustering

In the present study, we considered USA-based manufacturers SaMD landscape as shown in the Figure 1. Domestic market leaders included were Tandem Diabetes Care (San Diego, CA) [14], Insulet Corporation (Acton, MA) [15], Medtronic Diabetes (Northridge, CA) [16], and Dexcom Inc. (San Diego, CA) [17]. Geographic clustering was observed in California (San Diego, Northridge) and Massachusetts (Acton). International manufacturers included were Roche (Switzerland) and Ypsomed (Switzerland). Abbott, though a multinational corporation, is headquartered in the United States (Chicago, IL). Device sponsors and startups are also included predominantly in U.S. digital health hubs, particularly California and Massachusetts [18].

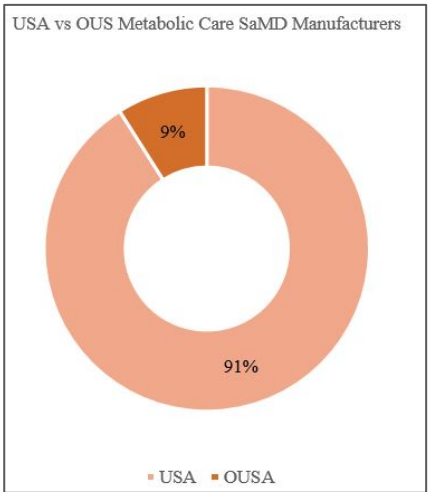

Figure 1: USA-based vs non-USA-based Diabetes SaMDs

Prescription Status and Technical Features

In the current study, we included majorly diabetes SaMDs that required prescription (Rx) authorization, particularly devices involved in insulin dosing calculations or therapeutic decision support. Over-the-counter (OTC) SaMDs were not considered as they are limited to educational tools, lifestyle modification support, and self-monitoring applications without autonomous dosing recommendations. We have clearly differentiated Regulatory labeling Rx from OTC products to ensure appropriate clinical oversight [8].

The technical features considered in the study for Continuous Glucose Monitoring (CGM)-integrated devices are factory-calibrated, minimally invasive sensors that provide 14 to 30 days of continuous glucose tracking along with real-time glycemic alerts [17, 19]. Recent CGM developments have enabled adaptive insulin dosing, integrated mobile applications, and telehealth connections. These improvements supported both sensor-based and capillary confirmation workflows [20]. In the current study, it has been noticed that Adaptive SaMDs like Omnipod 5, CamAPS FX, and Control-IQ Technology show better CGM integration and dynamic insulin dosing capabilities compared to non-adaptive tools like EndoTool and SmartBolus Calculator, which follow fixed dosing algorithms (Table 1). As a third-party platform compatibility, several SaMDs showed that they can integrate with third-party diabetes management platforms such as Huma, Livongo, mySugr, and Healthentia. This allowed data collection, telemedicine connections, and remote patient monitoring [18, 21, 22].

Regulatory Pathways and Timelines

Clearance Pathways and Device Classification

Of the 23 SaMDs, 22 (96%) received FDA 510(k) clearance based on substantial equivalence to existing devices, while 1 (4%) received De Novo approval (KidneyIntelX.dkd, DEN200052). The classification of devices included 22 (96%) Class II devices, which are considered moderate risk and have general and special controls, and 1 (4%) Class III device, which requires premarket approval and extensive clinical data [8, 23]. Whereas, among the adaptive devices (n=5), all received 510(k) clearance, and none required De Novo approval. The one De Novo device (KidneyIntelX.dkd) was not adaptive. The FDA granted Breakthrough Device designation to certain SaMDs that addressed unmet clinical needs through faster review processes [24].

Approval and Reapproval Timelines

In this study, the Initial approval timelines from FDA submission to clearance taken from 6 to 24 months based on factors like device complexity, how sufficient the clinical evidence was, and risk classification [8, 25]. Fig. 2 shows reapproval timelines across medical specialties for devices that need regulatory review after adaptation.

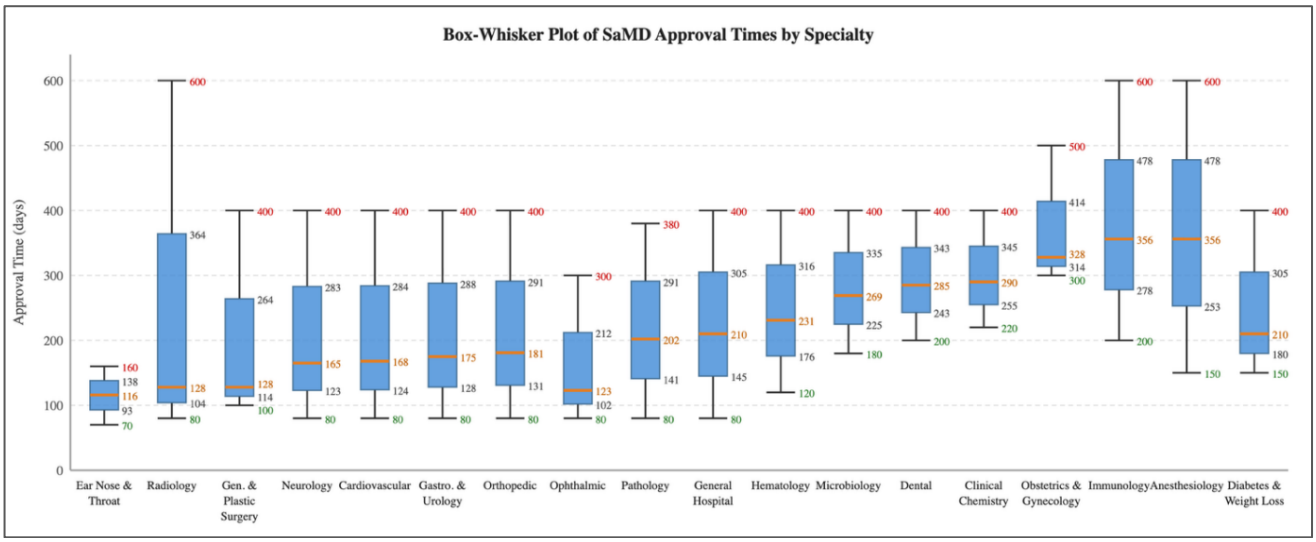

Figure 2: Regulatory Reapproval Timelines by Medical Specialty

It was noticed that Diabetes and metabolic care SaMDs had reapproval timelines between about 150 and 400 days, with a median of 210 days. This is similar to the timelines in General Hospital and Clinical Chemistry specialties. Ear Nose and Throat devices had the shortest reapproval range, which was 70 to 160 days. Of all, Radiology showed the most variability, ranging from 80 to 600 days. Anesthesiology and Immunology had the longest median durations, around 356 days each. For devices with documented algorithm changes that required regulatory resubmission, reapproval after modifications took between 6 and 12 months. These observations are depended on the scope of the modifications and the regulatory pathway used [26, 27].

Medical Specialties and Regulatory Controls

In our study, Device clearances were classified across endocrinology, internal medicine, family medicine, pediatrics (CGM and insulin pump applications) [28], cardiology (metabolic syndrome solutions) [29], nephrology (KidneyIntelX.dkd), and psychiatry (behavioral management modules). All 23 devices (100%) considered were subject to FDA general controls including device registration, labelling with indications/contraindications/warnings, and mandatory adverse event reporting protocols [8].

Special controls applied to Class III devices and adaptive SaMDs, including post-market surveillance requirements, cybersecurity safeguards, software validation protocols, and pediatric testing where applicable [8, 23]. The need for enhanced analytic validation was particularly pronounced for adaptive, autonomous devices providing automated insulin dosing given their potential for real-time clinical decision-making [30]. Human factors engineering validation was considered as mandatory for devices with autonomous dosing capabilities.

Clinical Trial Evidence

Trial Availability and Study Designs

It was showed in Figure 3, that a subset of SaMDs Omnipod 5, CamAPS FX, Control-IQ Technology, WellDoc BlueStar, EndoTool IV/SubQ, and InPen Dose Calculator had established clinical trial results available in publicly accessible databases, however, the majority of devices did not have published trial data in the registries that were searched.

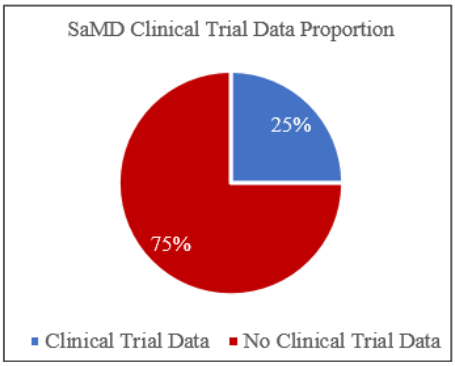

Figure 3: SaMDs With/Without Published Clinical Trial Data

Study Designs: Among devices with available trial data, interventional studies predominated over observational designs (Fig. 4). Diabetes SaMD clinical trials employed increasingly multicenter, randomized controlled, or pragmatic designs [12, 31]. Sampling methods included stratified, convenience, and adaptive schemes, reflecting device complexity and target populations. Study arms usually compared adaptive SaMD intervention with standard care or other devices.

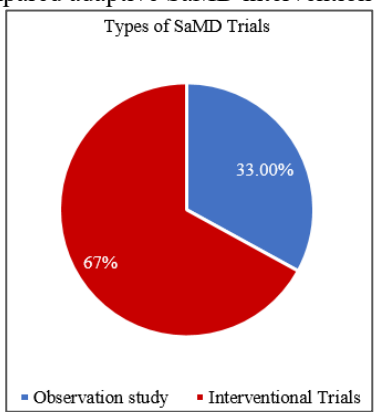

Figure 4: Interventional vs. Observational Trial Designs

Sample Characteristics and Demographics

Enrolment numbers and trial site distributions for selected SaMDs with clinical trial data are shown in **Fig. 5**. In the current study, Trial sites have been included with single-centre studies and multi-site investigations with more than 40 locations.

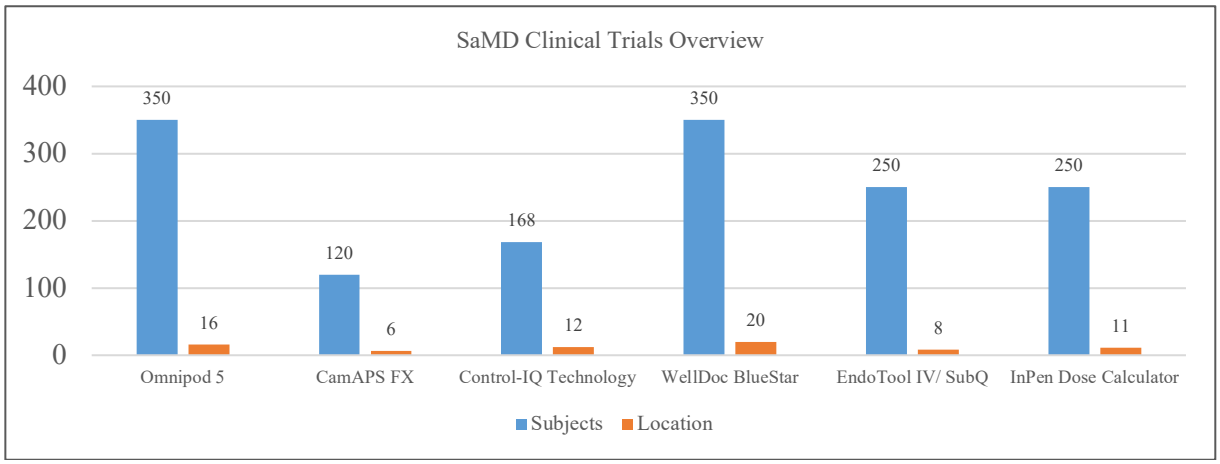

Figure 5: Subject Enrolment and Trial Sites by Device

Age Distribution: As shown in **Fig. 6**, adults aged 18 to 64 years made up most of the participants in diabetes SaMD clinical trials. Both pediatric groups (under 18 years) and older adults (65 years and over) were less represented. Participant ages ranged from below 17 to 75 years [28].

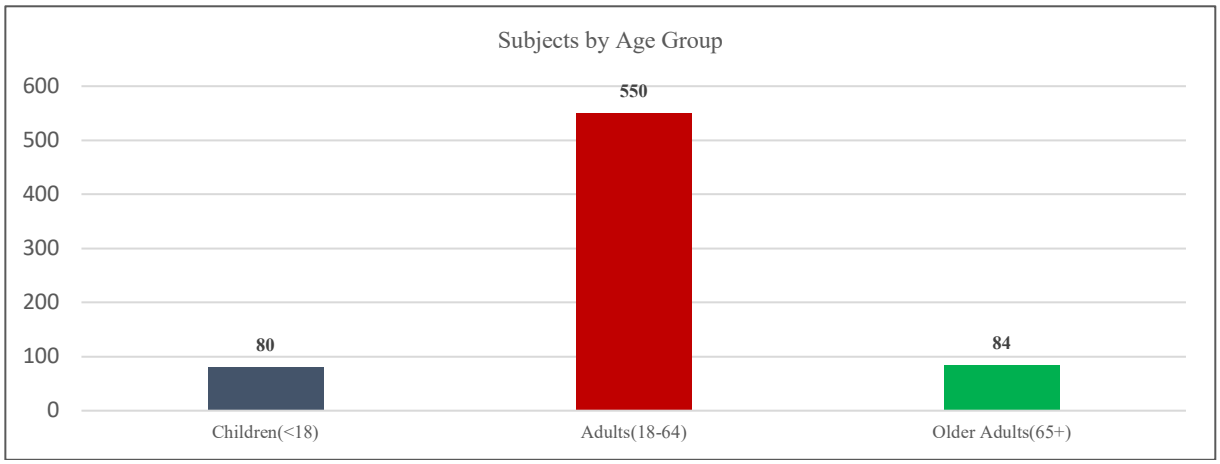

Figure 6: Clinical Trial Enrolment by Age Group

Inclusion criteria was considered based on a confirmed diabetes diagnosis, HbA1c levels, and comorbidity filters. The assessed covariates included sex, race, age, blood pressure, and biomarkers like TNF-α and GLP-1 agonists [32].

Geographic Distribution and Endpoints

As given in Fig. 7, Clinical trial locations included were mostly the United States, with additional sites spread across the United Kingdom, Germany, Canada, Australia, France, India, and Japan,

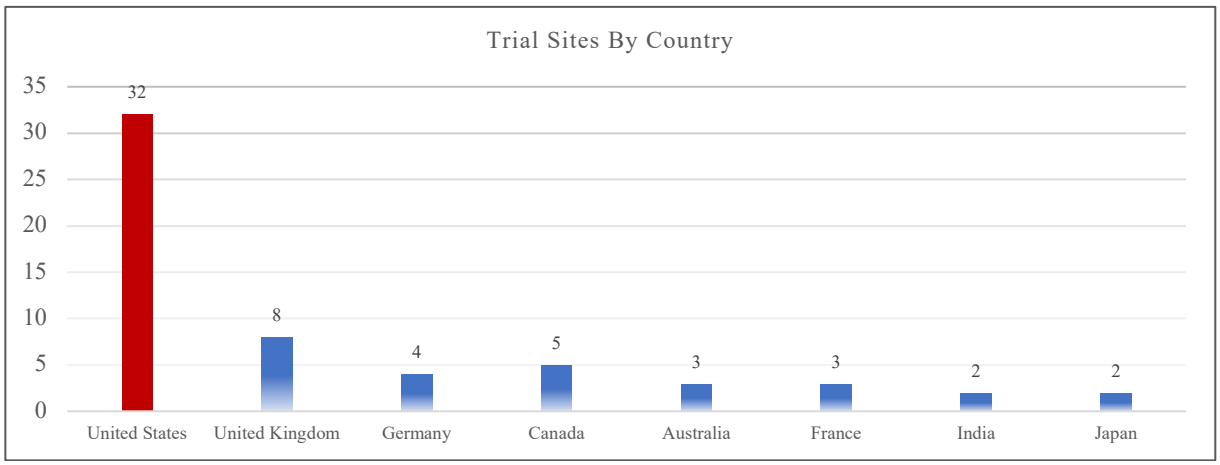

Figure 7: Distribution of Clinical Trial Locations by Country

Geographic distribution included North America, Europe, and Asia. This shows efforts to harmonize regulations and improve market access.

Primary Endpoints: Key studies were the Omnipod 5 pivotal trial, Control-IQ multicenter studies, and CGM accuracy validations [12, 33, 19]. Common primary endpoints included were, the metrics for glycemic control (like HbA1c reduction and time in range), frequency of hypoglycemic events, measures of device accuracy (mean absolute relative difference for CGM), and user satisfaction scores.

Precision Metrics: CGM-integrated devices reported mean absolute relative difference (MARD) values to indicate glucose monitoring accuracy. Precision studies were the main method for comparing devices, while simulation studies looked at user error patterns and how solid algorithms are [34, 35]. The 'hook effect' was rarely reported in the current study, but it was noted in cases of extreme biomarker levels impacting sensor calibration [32]. Survival outcomes were analyzed using Kaplan-Meier methods to evaluate event-free survival, device retention, and long-term complication rates [36].

Safety and Post-Market Surveillance

Recall History and Device Malfunctions

FDA MAUDE database analysis found device recalls among the 23 SaMDs from January 2004 to December 2024 [8]. The reasons for recalls included software bugs, algorithm errors, cybersecurity issues, and problems with data transmission. The recall reports noted quick responses from manufacturers, fast notifications to regulators, and updates to correct the products. While, device-related malfunctions such as ‘software errors’ or ‘CGM connectivity loss’ accounted for approximately 4% of adverse event reports and were linked to ‘missed doses’ or ‘erroneous dosing guidance’ [37]. Malfunctions included CGM connectivity loss, incorrect dosing guidance, software crashes, and data transmission errors.

Adverse Events and Safety Profiles

Table 2 presents indications, contraindications, warnings, and adverse reactions for 23 SaMDs used in metabolic care, covering both software and integrated hardware where relevant.

Table 2: Summary of Indications, Contraindications, Warnings, and Adverse Reactions

S.No	SaMD	Indication	Contraindication/ Usage Limitation	Warnings and Precautions	Adverse Reactions
1	Omnipod 5 Automated Insulin Delivery System	Automated insulin delivery for patients with diabetes using compatible CGM	Do not use with hydroxyurea; remove before MRI/CT	Risk of hypo/hyperglycemia; monitor for skin irritation, DKA, device malfunction	Allergic contact dermatitis, skin reactions, severe hypo/hyperglycemia, rare DKA
2	Camaps FX	Automated insulin dosing for T1D using CGM	Not for hospital use; avoid if use cannot respond to alerts	CGM accuracy; connectivity failure	Skin reactions, rare severe hypo/hyperglycemia

3	Control-Iq Technology	Adaptive insulin dosing for T1D using CGM	Not for children under 6 years or weight <25 kg	Risk of device/pump malfunction, missed alerts	Hypoglycemia, hyperglycemia, device alarm fatigue
4	D-Nav System	Personalized insulin dosing for diabetics	Not for patients under 18 or with gestational diabetes	Monitor settings, renal/liver function	Hypoglycemia, hyperglycemia
5	Edge (Glytec)	Clinical decision support for dosing	Avoid in terminal patients or those with insulin allergy	Need for clinical oversight, hypoglycaemia risk	Hypoglycemia
6	Welldoc Bluestar (Diabetesmanager)	Digital therapeutic support for T2D	Not for gestational diabetes or insulin pump users	Not a replacement for clinical care; data accuracy	No serious reactions, rare user confusion
7	Clarian Glucose Stabilizer	Insulin dose calculator for diabetes	Not for patients under 18 years	Correct use and validation of data	Erroneous dosing from user error
8	Endotool IV 1.10 / Subq 2.1	Clinical decision support for IV/subQ insulin dosing (hospital)	Do not start if potassium <3.5 mEq/L; not for <2 years	Requires trained operator; monitor for user/dosing errors	Hypoglycemia, inappropriate dosing
9	Freestyle Auto-Assist Software Version 2.0	CGM-based dosing for diabetes	No specific contraindications	Confirm device accuracy, do not ignore alarms	Rare transmission error, minor skin reactions
10	Glucofacts Express Diabetes Mgmt Software	Guidance for diabetes management	No specific contraindications	Evaluate algorithm suitability for patient	No serious reactions reported
11	Glucommander Plus	Inpatient insulin dosing support	Not for patients under 18 years	Must review dosing suggestions; not automatic	Incorrect dosing due to user error
12	Go Dose System	Insulin dosing via pharmacokinetic model	Only for Humalog U-100 users; not for other insulins	Correct settings; not a replacement for clinical judgment	Rare skin reactions, occasional dosing errors
13	Health E-Connect System	Data aggregation for diabetes mgmt	Not for insulin pump users	Confirm device settings	Rare data inaccuracy
14	Inpen Dose Calculator	Insulin dose calculation for smart pen users	Not for patients under 12 years; MDI only	Confirm each dose; check app updates	Dosing errors, rare app malfunction
15	Insulia Bolus Companion	Bolus recommendations for diabetes	Not for pregnancy; basal-bolus only	Validate patient parameters	Occasional dosing errors if used incorrectly
16	My Insulin Doser (Intelligent Dosing System)	Calculator-based insulin dosing	No specific contraindications	Double-check all dosing; do not replace clinical judgment	Rare dosing errors
17	Kidneyintelx.Dkd	Risk stratification for diabetic kidney disease	Not for non-CKD patients or screening use	Not diagnostic; supplement to clinical decision	Diagnostic inaccuracies if misused
18	My Dose Coach	Dose recommendations for diabetics	No specific contraindications	Keep user parameters updated; validated data only	Rare user errors, minor skin reactions
19	Onetouch Zoom Diabetes Management Program	Data management/decision support for diabetes	No specific contraindications	Ensure data security/privacy; accuracy before decisions	Rare data breaches, technical issues

20	Pill Phone	Adherence/reminder support	No specific contraindications	Use as reminder only; not sole med record	Missed doses if user ignores reminders
21	Precision Link Diabetes Data Mgmt System	Clinical data management platform	No specific contraindications	Confirm data before clinical decisions	No serious reactions reported
22	Smartbolus Calculator	Portable bolus dosing for diabetes	Not for children under 2 years; U-100 insulin only	Use with accurate, validated data	Occasional incorrect dosing
23	Sparse Sample PK Profile And Dosing Software (Mypkfit)	PK-based insulin dosing recommendations	Not for patients under 16 years or weight <45 kg	Validate PK model suitability for patient	Rare mis-dosing, software errors

Analysis of warning patterns across 23 SaMDs revealed the following adverse event frequencies:

1. Severe Hypoglycemia: Hypoglycemia represented the most common and severe adverse risk, with rates of severe hypoglycemia among insulin pump and dosing system users reported at 2-5 episodes per 100 patient-years in clinical trials [38].
2. Device Malfunctions: Software errors or CGM connectivity loss made up about 4% of adverse event reports. These were linked to missed doses or wrong dosing guidance [8, 37].
3. Data Entry Errors: Data entry errors occurred in up to 11% of user interactions. This led to incorrect dosing in 1-2% of cases [39].
4. Allergic Skin Reactions: Allergic skin reactions, including contact dermatitis, affected 5-8% of users of wearable devices like CGM sensors and insulin pump infusion sites. Some users needed to stop using the devices [27].
5. Privacy and Data Security Breaches: Breaches of privacy and data security were rare. They accounted for less than 1% of adverse reports, showing strong regulatory protections [8].
6. Medication Errors in Vulnerable Populations: Misuse in vulnerable groups, such as children or those with kidney problems, caused up to 3% of medication errors in hospitals. This led to updates in both software algorithms and clinical workflows [39].
7. Labeling Emphasis: Over 90% of FDA labeling for all SaMDs highlighted that these devices are meant to support, not replace, clinician judgment. This reinforces the need for professional oversight in making treatment decisions [37].

Pediatric Safety Considerations

In the present study, Pediatric SaMDs primarily focused on CGM integration, insulin pump control, and telemonitoring applications [17, 16]. It was noticed that regulators paid special attention to pediatric groups. They highlighted the need for age-appropriate algorithms, developmental factors in dosing, and endpoints that included the psychosocial impact and caregiver education requirements [28]. Pediatric devices underwent stricter safety reviews because of developmental sensitivities, changing dosing needs, and a higher risk of dosing errors [40]. The Humanitarian Device Exemption and Real-World Evidence initiatives helped speed up pediatric device approvals [8]. It was identified that multicenter trials focusing on outcomes in children under 17 remained were very limited compared to studies focused at adults.

Human Factors Engineering and Technical Features Cybersecurity Protocols

In our study, it was observed that the regulatory requirements required strong cybersecurity measures for SaMDs, including end-to-end encryption, secure data transmission protocols, and complete incident response plans to protect against unauthorized access and breaches [8, 26]. Privacy and data security breaches made up less than 1% of adverse event reports, showing effective risk management through regulatory protections [8].

User Experience and Error Minimization

In the current study, it was analysed that Human factors engineering played a key role in improving user experience and reducing error rates for SaMDs. A systematic evaluation of usability, workflow integration, and patient engagement made sure that devices were easy to use and helped lowering the chances of data entry mistakes, missed alerts, or disengagement [41, 35]. Data entry errors were noted up to 11% of user interactions. This led to incorrect dosing in 1-2% of cases, highlighting the need for ongoing improvements in software design and user training [39]. Device-related problems like software errors or loss of connectivity noted for about 4% of adverse events. This shows how important it is to monitor errors and have quick solutions in place.

Medication Adherence Enhancement

Fig. 8 shows how we selected SaMDs influence medication adherence in the study. They are scored from 1 to 5 based on information from manufacturers, FDA reports, and peer-reviewed studies.

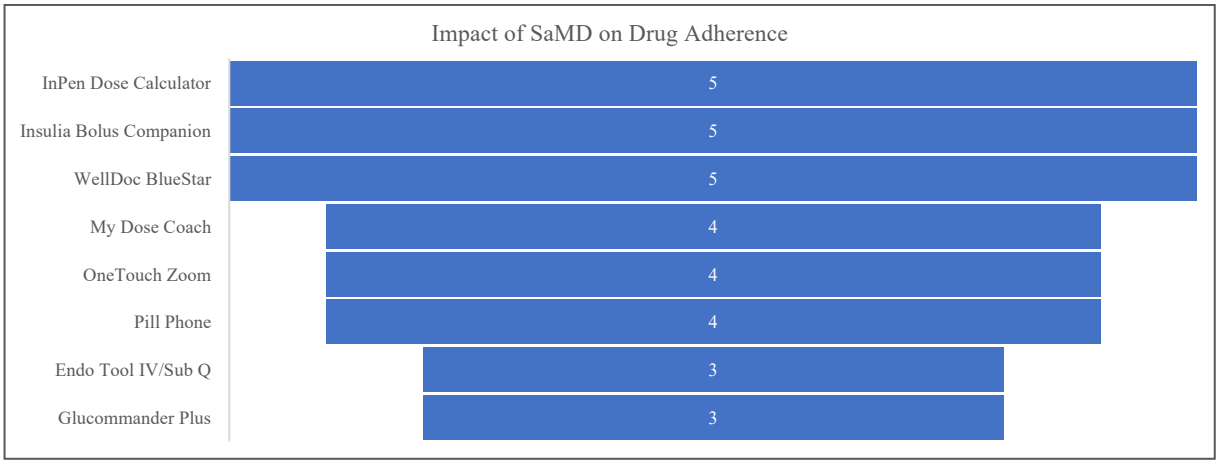

Figure 8: SaMDs Promoting Drug Adherence, Scored 1-5

It was noticed that digital therapeutics and SaMDs improved adherence by using reminders, education modules, and tele pharmacy feedback mechanisms [42]. Integrating with CGM and smart dosing platforms reduced the missed doses and supported lifelong self-management for various patient groups [18]

Discussion

From the above results, this research on 23 FDA-cleared SaMDs for diabetes and obesity management noticed several important findings. The regulatory landscape is mainly shaped by 510(k) clearance pathways, which account for 96%, and Class II device classifications, also at 96%. However, AI-driven SaMDs require closer regulatory attention. Approval timelines were considered from 6 to 24 months, and reapproval after adaptation took 6 to 12 months, showing variation specific to each speciality. Clinical trial evidence was available only for some devices, with a focus on interventional designs, that includes adult patients. Severe hypoglycemia, which occurs in 2 to 5 episodes per 100 patient-years, and device malfunctions, which make up 4% of adverse events, were the main safety issues. Data entry errors were identified to 11% of user interactions. Manufacturers based in the USA were mainly located in California and Massachusetts, with little international presence. Key measures like human factors engineering and cybersecurity were important in meeting regulatory requirements, but how they were put into practice varies among devices.

Interpretation in Terms of Research Objectives

Regulatory Pathways and Timelines

The increased percentage of 510(k) clearance, almost to 96%, shows the common regulatory strategy for SaMD market entry. However, depending on predicate-based pathways raises concerns about their suitability for adaptive algorithms. These algorithms are different from static predecessors because they can modify themselves. It was noticed that the lack of De Novo authorizations for adaptive devices stands out, especially since FDA guidance indicates that new AI/ML-based SaMDs may need de novo pathways [13]. This situation might reflect manufacturers choosing pathways that speed up approval or changes in regulations since the clearances of these devices.

The reapproval timelines for diabetes SaMDs average 210 days, which aligns with the General Hospital and Clinical Chemistry specialties. However, there is a lot of difference in these timelines, ranging from 150 to 400 days. This highlights existing issues in standardizing regulatory processes for changes to algorithms. Reapproval takes significantly longer in Anesthesiology and Immunology, around 356 days, suggesting that specific complexities in specialties need further investigation to aid standardisation efforts. This observation is in accordance with observations of Lakhan[37].

Clinical Evidence Quality and Availability

It was noticed that limited availability of published clinical trial data for most researched SaMDs created a significant evidence gap. While 510(k) clearance may not require extensive clinical trials, the lack of publicly available efficacy and safety data slows down evidence-based clinical adoption and post-market surveillance [31]. Among devices with trial data, the focus on interventional designs over observational ones shows a regulatory preference for controlled comparisons. From the above findings it was observed that, the low representation of pediatric participants and older adults limits how well findings apply to vulnerable groups. The concentration of trials in the United States, with some participation from Europe, restricts applicability to diverse global populations, especially in low and middle-income countries where diabetes and obesity rates are rising [1, 2]. As per the studies of Braune et al and Philis-Tsimikas et al Pragmatic trial designs, adaptive sampling methods, and real-world evidence generation are the promising ways to tackle these limitations [31, 34]. From the current study it was evident that standardizing endpoints and precision thresholds across SaMDs could improve comparisons between devices and guide regulatory standards and the findings are in agreement with the observations of Lutsker et al[32].

Safety Profile and Adverse Events

Severe hypoglycemia is the main safety concern and matches the known risks of insulin-based diabetes treatments [5]. From the above observations, it was noticed that the rate of 2-5 episodes per 100 patient-years needs to be understood in the context of traditional therapies, but most trials did not include direct comparisons. Device malfunctions account for 4% of adverse events, and data entry errors make up 11% of user interactions. These issues point to ongoing challenges in software reliability and human-device interface design [23, 41]. From the study results it was observed that the high rate of data entry errors suggests that current interface designs do not effectively support real-world usage. This calls for ongoing usability testing and integration of feedback after products reach the market.

Privacy and data security breaches are reported in less than 1% of adverse reports. These numbers indicate that regulatory protections and manufacturer cybersecurity measures are working [8]. From the above findings, it was noticed that adapting to new threats and the growing connectivity of devices requires constant attention. Medication errors occur in at-risk groups, especially in pediatric patients and those with kidney issues, affecting up to 3% of cases. This highlights the need for algorithms tested for specific populations, clear warning labels, and required training for clinicians as given in the previous study by John et al [39]. The FDA's note that over 90% of software as a medical device (SaMD) is meant to supplement clinical judgment rather than replace it is a sound approach to reducing risk. However, putting this into practice depends on clinician awareness and strong institutional measures to prevent complacency with automation is required.

Adaptive vs. Non-Adaptive Device Considerations

While all five adaptive devices received 510(k) clearance, adaptive algorithms that learn from patient data present unique challenges. These challenges include a lack of transparency, unpredictable behaviour in unusual situations, data changes requiring revalidation, and increased cybersecurity risks [13, 30]. In the previous study by Talari et al, it was mentioned that current regulatory guidelines, designed mainly for static devices, might not fully cover these specific risks related to adaptiveness [43]. But as per the current study, the FDA's AI/ML-based SaMD Action Plan suggests that plans for managing changes that would allow algorithm updates without needing a complete premarket review, but this approach is still in early stages, the time it takes to reapprove algorithm changes, which can range from 6 to 12 months, indicates a significant regulatory burden. This burden could hinder innovation in adaptive systems, despite their potential benefits in treatment.

Geographic Clustering and Pediatric Device Development

Geographic clustering of SaMD manufacturers in California and Massachusetts shows how these areas combine venture capital, academic medical centers, regulatory expertise, and talent pipelines [18]. However, this concentration raises concerns about global representation in device development priorities and fair access to innovative therapies in non-U.S. markets. While international manufacturers contributed, they remained secondary to U.S. dominance. This trend suggests that the broader digital health patterns contrasts with the global distribution of diabetes and obesity burdens [1]. It was analysed that the underrepresentation of pediatric participants and the limited number of pediatric-specific SaMDs result from various barriers. These include ethical constraints, smaller market sizes, developmental differences that complicate algorithm design, and increased regulatory scrutiny [28, 40]. From the results it was confirmed that validating age-appropriate algorithms must consider physiological differences and developmental needs in user interface design, caregiver control allocation, and psychosocial factors beyond just glycemic metrics as suggested by Torous et al [28].

Implications for Stakeholders

Regulatory Agencies: As per US FDA, developing guidance for adaptive algorithms that addresses change control plans, continuous learning validation, and algorithm transparency would help manufacturers and ensure proper oversight [13]. From the above results it was evident that standardizing reapproval processes across specialties and encouraging pediatric software as a medical device (SaMD) development through longer exclusivity or simpler pathways may fill existing gaps.

Clinicians and Healthcare Systems: It was identified from the above results that educating on SaMD capabilities, limitations, and proper clinical integration is key to maximizing therapeutic benefits and reducing risks. Institutions should have safeguards against automation bias to maintain clinician-patient relationships and professional oversight while making use of SaMD data analytics [36].

Manufacturers: It was noticed that focusing on user-centered design, ongoing usability testing, and including a diverse group of users during development is crucial to minimize data entry errors and improve real-world effectiveness that is aligned with the observations of Gonder-Frederick et al [41]. Clear reporting of clinical trial results, regardless of regulatory requirements, would support evidence-based adoption. Taking proactive steps for cybersecurity and managing the software lifecycle is vital in an evolving threat environment [26].

Policymakers: As per the previous studies, addressing digital equity issues such as broadband access, affordable devices, digital literacy support, and culturally suitable interfaces is necessary to unlock the population health potential of SaMDs [21]. Hence it was suggested that reimbursement policies need to change to recognize the value of SaMD beyond traditional models, possibly including value-based arrangements linked to clinical outcomes.

Study Limitations

- This study concentrated only on FDA-cleared devices and which has no global applicability of findings.
- Because study depended only on publicly available data, devices not having published evidence or trial registration may not have been fully represented.
- Algorithmic complexity is not fully represented because of the simplified classification(there is no inclusion of semi-adaptive), i.e., adaptive versus non-adaptive representation.
- Because the cross sectional analysis of SaMD spanned two decades hence changes in regulatory practices over time might have not been fully reflected in this study.
- This study highlights only the regulatory and clinical trial pointers and did not evaluate real word effectiveness, patient reported outcomes, and health economic impacts.
- As the SaMD landscape is rapidly evolving, the findings represented in the current study may be outdated

Future Research Directions

Future research should focus on a few important areas. It is helpful to do studies that directly compare adaptive and non-adaptive SaMDs to see which works better. Checking if everyone has equal access to these technologies is important, so studies should look for any gaps among different groups. For children, there is a need to create algorithms that suit their age and check if they work well as children grow. Research should also follow up on patients for a longer time than usual trials to see long-term effects. It is valuable to study different ways to approve these devices and see if flexible licensing models help. Lastly, with new threats always coming up, we must keep learning about how to protect medical devices and fix any weaknesses in their systems.

Conclusion

This research shows how regulations are enabling significant changes in patient care while keeping safety standards. These devices changed diabetes management from occasional doctor visits to continuous support through glucose tracking, automatic insulin adjustments, and personalized guidance. They bring hospital-level tools to home settings, however, the safety analysis highlighted key points. Serious complications such as low blood sugar can be managed with minimal awareness about oneself and privacy breaches remained below one percent. The user interface errors impacted about one in ten interactions, indicating that design improvements are needed. Despite these issues, the benefits for patients are evident for sure. They enjoy real-time health data, immediate treatment recommendations, and ongoing support. The future improvements in technology supervision, better user interfaces, global pediatric testing, and availability will represent progressive steps toward adaption.

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