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Factors Affecting Continuous Glucose Monitoring Results: A Meta-Analysis

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Abstract

Since its introduction, continuous glucose monitoring (CGM) has achieved good benefits in clinical blood glucose monitoring and self-blood glucose management for diabetic patients. However, during the usage process, there are various interfering factors, among which there are more or less controversial ones. This study evaluated the impact of these factors on the accuracy of continuous glucose monitoring (CGM). A meta-analysis was conducted on a type of observational study that used continuous glucose monitoring (CGM) to monitor blood glucose levels in individuals diagnosed with or undiagnosed for diabetes. A total of 526 articles were retrieved from four electronic databases. By using EndNeto software to exclude ineligible data, 425 articles were eliminated. For the remaining 101 articles, information such as the title, author, and publication year of each document was entered into the system, which automatically identified and excluded 14 duplicate studies. In the end, the remaining 87 articles were carefully reviewed. Of these 87 studies: 17 were animal experiments, 31 involved research on individuals under 18 years old, 14 were missing articles, and 15 were reviews. Ultimately, 11 studies met our requirements for analysis. The results of the heterogeneity test showed that the data was heterogeneous (χ^2: 3438.01, I^2 = 99.7%, p = 0.266 > 0.05). Statistical analysis was conducted using the fixed-effect model, and there was no publication bias. It is indicated that with the continuous update of science and technology, fewer and fewer factors that are considered likely to affect the results of continuous dynamic blood glucose monitoring will be reduced and eliminated. As a result, more advanced, convenient, efficient and accurate continuous dynamic blood glucose monitoring methods will benefit humanity. To provide an effective basis for accurately judging the blood glucose levels of diabetic patients, and to offer effective guidance for patients in aspects such as correct exercise, diet control, and pancreatic islet use in blood glucose self-management.

Keywords

Diabetic Patients, Continuous Dynamic Blood Glucose Monitoring, Influence

1. Introduction

Diabetes is a group of heterogeneous diseases, commonly characterized by elevated blood glucose levels, or hyperglycemia. It can be classified into Type 1 diabetes and Type 2 diabetes. Type 1 diabetes (T1DM) results from immune-mediated destruction of pancreatic β-cells, leading to impaired insulin secretion, and is mostly characterized by absolute insulin deficiency. Type 2 diabetes (T2DM) involves reduced insulin action (insulin resistance) along with progressive loss of β-cell function, typically starting as relative insulin deficiency. This often results in disrupted glucose-dependent insulin secretion by the receptors. Both types can develop into severe hyperglycemic symptoms such as polyuria, thirst, fatigue, unexplained weight loss, vision impairment, and increased risk of infections, ketoacidosis or non-ketotic hyperosmolar syndrome, with potential for coma. Chronic hyperglycemia can also lead to dysregulation of insulin secretion and/or action, and is associated with long-term damage and functional impairments of various tissues and organs (eyes, kidneys, nerves, heart, and blood vessels) as well as cancer.

With the increasingly advanced development of treatment and monitoring technologies for diabetes patients domestically and internationally, there are some differences in the prevalence of diabetes across countries [1]. According to data from the National Health and Nutrition Examination Survey (NHANES) in the United States from 2013 to 2023, the prevalence of diabetes among adults has not shown a significant increase. However, patients who have been diagnosed with diabetes have experienced worsening conditions after 10 years. In China, the incidence of diabetes is also rising annually, with Type 2 diabetes (T2DM) being predominant [2]. It is particularly important to manage diabetes patients both in hospitals and at home due to the large number of cases. Poor management that leads to consistently high or low blood glucose levels in diabetes patients can cause irreversible damage to target organs and even result in life-threatening complications [3]. Therefore, it is crucial for diabetes patients to continuously and stably monitor their blood glucose levels and maintain them within the prescribed normal range. However, traditional blood glucose monitoring techniques often involve invasive procedures, causing discomfort and pain to patients, which decreases their compliance and motivation for self-monitoring. Diabetes patients need a precise and comfortable way to monitor blood glucose in order to improve their quality of life. The development of continuous glucose monitoring technology can address this issue and provide significant relief for such patients [4].

Continuous dynamic blood glucose monitoring (CGM) refers to the technology

that continuously monitors glucose concentrations in the interstitial fluid of subcutaneous tissue through glucose sensors [5]. This technology provides continuous, comprehensive, and reliable 24-hour blood glucose information, helping to understand the trends and characteristics of blood glucose fluctuations. It enables effective blood glucose monitoring and better management for diabetes patients, and is favored by clinical patients, doctors, and nurses [6]. However, the results from continuous glucose monitoring (CGM) can also be influenced by certain factors [4]. This study aims to consider and eliminate these influencing factors, allowing for more systematic and optimized management of patients' blood glucose levels. It involves a comprehensive systematic evaluation and analysis of recent research on CGM, providing a reliable evidence-based basis for clinical blood glucose management.

2. Methods

2.1. Inclusion and Exclusion Criteria

1) Inclusion Criteria: a) Participants aged ≥ 18 years; b) Populations diagnosed with diabetes or not yet diagnosed with diabetes; c) Diabetes patients who are receiving or not receiving treatment; d) Observational studies.

2) Exclusion Criteria: a) Individuals who cannot understand or refuse to use continuous glucose monitoring; b) Less than 70% usage time of continuous glucose monitoring; c) Participants with impaired decision-making capacity or without decision-making capacity; d) Participants who have died or whose continuous glucose monitoring data is missing.

2.2. Literature Retrieval Strategy

Computer searches were conducted in PubMed, Embase, Web of Science, and the Cochrane Library, with a search period covering from the establishment of each database until March 2025. The search employed English subject terms combined with advanced search strategies. The search query was: Advanced search ((((((Continuous dynamic blood glucose monitoring, influence factor) OR (Interstitial fluid blood glucose, influence factor)) AND ((Continuous dynamic blood glucose monitoring, management) OR (Interstitial fluid blood glucose, management) OR (Freestyle Libre, influence factor) OR (Freestyle Libre, management)))))). Subject term search: "Continuous dynamic blood glucose monitoring" [Mesh] AND (influence factor, management). Search results yielded a total of 526 articles, which were included in the meta-analysis. The search process is illustrated in **Figure 1**.

2.3. Search Results

We retrieved a total of 526 articles from four electronic databases. Using EndNeto software, we excluded 425 ineligible articles. For the remaining 101 articles, we entered information such as the title, author, and publication year, and the system automatically identified and excluded 14 duplicate studies. Finally, we conducted

an in-depth review of the remaining 87 articles. Among these: 17 were animal experiments, 31 were studies involving participants under 18 years old, 14 articles were missing, and 15 were reviews. Ultimately, 11 studies met our requirements and were included for analysis.

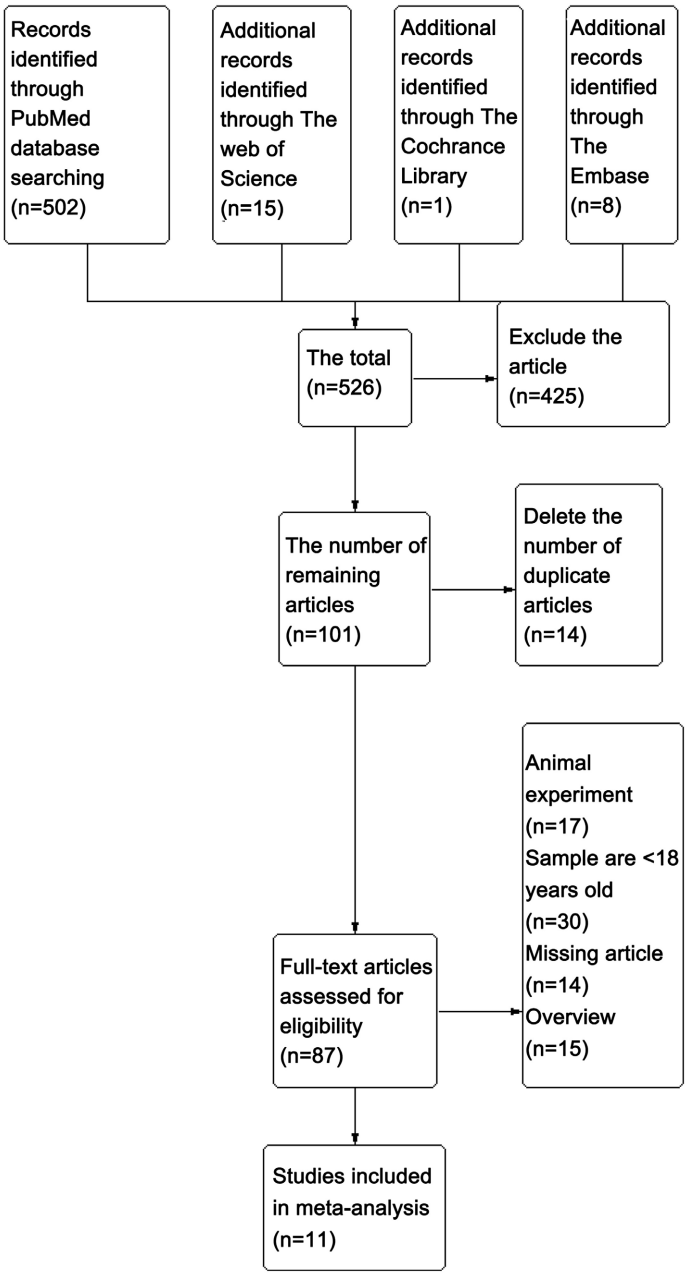

Figure 1. Flowchart of literature screening.

2.4. Data Extraction

The research team for this study consisted of four members. During the retrieval and analysis of articles, three researchers selected articles and extracted data based on inclusion and exclusion criteria. They then cross-verified the selections. If any

contentious issues arose, the other three researchers were consulted to resolve them. Articles were preliminarily included by reviewing their titles and abstracts. After identifying and excluding duplicate articles, each article was then read in detail to finalize the selection of appropriate articles. Data were extracted from these chosen articles and included information such as: author, country, publication year, study type, sample size, statistical tests (M ± SD), and outcome indicators. This information was compiled into a summary table, such as **Table 1**. The primary outcome indicator was MARD (Mean Absolute Relative Difference); the smaller the value, the more accurately continuous glucose monitoring reflects glucose levels [7]. Secondary outcome indicators included Time in Range (TIR) %, Glycemic Variability (CG-MBY), Precision Absolute Relative Difference (PARD), etc. as detailed in **Tables 1-4**.

Table 1. Diagram of general characteristics.

Author	Year	Country	Study Subjects	Study Type	Follow-up Duration	Influencing Factors	Non-exposed Group (Control Group)			Exposed Group (Experimental Group)			Total Sample Size	P-value
							Non-exposed (Experimental Group) Sample Size (Control Group)	Non-exposed (Experimental Group) Outcome Indicator (MARD %)	Non-exposed Group Standard Deviation	Exposed Group Sample Size (Experimental Group)	Exposed Group (Control Group) Outcome Indicator (MARD %)	Exposed Group Standard Deviation		
Hanson K; Kipnes M [8]	2024	America	≥18 years old Type 1/Type 2 Diabetes Patients	Cohort Study	60 Days	Product Performance	3640	13.6	9.4	4020	8.9	0.6	7660	P < 0.0001
Avari P; Tang W; Jugnee N [9]	2023	Britain	Adult Diabetic Hemodialysis	Cohort Study	28 Days	Product Performance	2656	22.7	3.4	2785	11.3	2.7	5441	P < 0.0001
Toyoda M; Murata T [10]	2021	Japan	Adult Diabetic Hemodialysis	Cohort Study	16 Days	HD	447	21.7	12.2	2438	25.8	11.9	2885	P < 0.005
Narasaki Y; Kalantar-Zadeh K [11]	2024	America	Adult Diabetic Hemodialysis	Case-Control	7 months	HD	243	20.3	13.4	233	20.7	12.3	476	P > .005
Villard O; Breton MD [12]	2022	America	Adult Diabetic Hemodialysis	Case-Control	578	HD	624	14.3	9.8	684	13.8	9.23	1308	P < 0.005
Matzka M; Ørtenblad N [13]	2024	Germany	Adult	Case-Control	—	Exercise	199	17.5	13.2	101	18.1	13.3	300	p ≤ 0.02
Villa-Tamayo MF; Builes-Montaño CE [14]	2024	America	Adult Type 1 Diabetes	Case-Control	28 Days	Calibration	27286	17.49	13.15	26979	12.06	20.22	54265	P < 0.005
Bauhaus H; Erdogan P; [15]	2023	Germany	Adult	Case-Control	14 Days	Exercise	519	22	24	519	18	17	1038	p < 0.001
Ólafsdóttir AF; Andelin M; [16]	2022	Sweden	Adult Type 1/2 Diabetes Advanced Chronic Kidney Disease	Case-Control	14 Days	Product Performance	33	15.2	12.2	33	20.9	8.6	66	P < 0.005
Eichenlaub M; Waldenmaier D [17]	2025	Germany	Adult Type 1 Diabetes	Case-Control	15 Days	Product Performance	2047	12	13.9	2002	11.6	13.4	4049	P < 0.005
Pleus S; Stuhr A; Link M [18]	2022	Germany	Adult Type 1 Diabetes	Case-Control	153 Days	Product Performance	24	13.2	2.4	24	12.5	3.6	48	P < 0.005

MARD: Mean Absolute Relative Difference; HD: Hemodialysis.

Table 2. Article quality evaluation form.

			Non-exposure group (control group)												Exposure group (Experimental group)										
Author	Year	Influencing factors	Non-exposure (experimental group) group Sample size (control group)	Blood glucose values in the non-exposed group	Time within blood glucose control range (TIR)% during hemodialysis	Hours within the blood glucose control range (TIR)% during the entire learning period	Non-exposure (Non-experimental group secondary outcome measure (CG-DIVA))	Non-exposed group Laboratory Reference value (YSI) reference value %	The reference ratio of capillary glucose in the non-exposed group was %	The MARD% of CGM in the non-exposed group at 0 to 12 hours and 12 to 24 hours	Pre-calibration (Non-exposure) Precision Absolute Relative Difference (PARD)"	Mean absolute Difference (MAD) of the non-exposed group	Standard deviation of mean absolute difference in the non-exposed group	Mean relative difference (MRD) in the non-exposed group	Mean relative difference (MRD) in the non-exposed group	Blood glucose levels of the exposure group	Time within the range of blood glucose control (TIR)% during hemodialysis"	Time within the range of blood glucose control (TIR)% during the entire study period	Exposure (Secondary outcome measure of the experimental group (CG-DIVA)	Exposure group Laboratory Reference Value (YSI) Reference value %	Reference ratio of capillary glucose in the exposure group: %	MARD% of CGM in the exposure group from 0 to 12 hours and 24 hours	Calibrated (Exposed) Precision Absolute Relative Difference (PARD)	Mean absolute Difference (MAD) of the exposure group"	Standard deviation of mean absolute difference in the exposure group
Hanson K;	2024	Product performance	3640	70 to 180 mg/dl	-	-	11.1	69.7	75.5	14.4	-	-	-	-	4020	70 to 180 mg/dl	-	-	0.6	71	15.8	14.5	-	-	-
				>180 mg/dl	-	-	5.5	20	15.8	15.1	-	-	-	-		>180 mg/dl	-	-	2.6	20	18.9	10	-	-	-
Avari P;	2023	Product performance	2656	70 to 180 mg/dl	27.4	33.2	-	-	-	-	-	-	-	-	2785	70 to 180 mg/dl	68.9	59.6	-	-	-	-	-	-	-
				>180 mg/dl	71.3	65.1	-	-	-	-	-	-	-	-		>180 mg/dl	30.5	35.6	-	-	-	-	-	-	-
Villa-Tamayo MF;	2024	Calibration	27,286	-	-	-	-	-	-	-	17.08	-	-	-	26,979	-	-	-	-	-	-	-	12.18	-	-
Ólafsdóttir AF;	2022	Product performance	33	-	-	-	-	-	-	-	-	1.21	0.78	-	33	-	-	-	-	-	-	-	-	1.76	0.78
Eichenlaub M;	2025	Product performance	2047	-	-	-	-	-	-	-	-	-	-	-	2002	-	-	-	-	-	-	-	-	-	-
Pleus S;	2022	Product performance	24	-	-	-	-	-	-	-	-	-	-	-	24	-	-	-	-	-	-	-	-	-	-

2.5. Quality Assessment

The methodological quality of non-randomized controlled trial designs was evaluated based on the Risk of Bias in Non-randomized Studies—of Interventions (ROBINS-I) tool, for quality assessment of the articles. The ROBINS-I scale uses a "dot system" to rate the included studies in three aspects: before intervention grouping, during intervention grouping, and after intervention grouping. The ratings include: Before intervention grouping—confounding bias, participant selection bias; During intervention grouping—intervention classification bias; After intervention grouping—bias due to deviations from intended interventions, missing data bias, outcome measurement bias, and selective reporting bias [19]. There are a total of seven components. If all components are rated as low risk, the study

is considered low risk. If any component is rated as moderate, high, or very high risk, the study is determined to be of the highest level of risk. If any component is rated as no information, the study is defined as having no information. Specific ratings are detailed in Table 5.

Table 3. Article quality evaluation form.

Author	Year	Influencing factors	Non-exposed group (Control Group)					Exposed group (Experimental group)				
			Non-exposure (experimental group) Sample size (control group)	Blood glucose values in the non-exposure group	Non-exposure (outcome measure MARD% of the experimental group)	Mean absolute Difference (MAD) of the non-exposed group	Standard deviation of mean absolute difference in the non-exposed group	Sample size of the exposure group (experimental group)	Blood glucose levels in the exposure group	Exposure (Outcome measure of the experimental group MARD%)	Mean absolute Difference (MAD) of the exposure group	Mean absolute Difference (MAD) of the exposure group
Toyoda M;	2021	HD	447	-	-	21.3	33.8	2438	-	-	30.5	17.1
Narasaki Y;	2024	HD	243	-	-	15.7	26.5	233	-	-	27.6	23.1
Villard O;	2022	HD	624	70 to 180 mg/dl	15.5	-	-	684	70 to 180 mg/dl	14.1	-	-
				>180 mg/dl	12.7	-	-		>180 mg/dl	15.3	-	-

Table 4. Article quality evaluation form.

Author	Year	Influencing factors	Non-exposure group (control group)			Exposure group (Experimental group)		
			Non-exposure (experimental group) Sample size (control group)	Eating high-carbohydrate before exercise (MARD%)	High-carbohydrate intake: Standard difference before exercise	Exposure (experimental group) Sample size (control group)	Eating high-carbohydrate exercise (MARD%)	Eating high-carbohydrate exercise with standard difference during exercise
Matzka M;	2024	Sports	199	15.7	14.1	101	17.1	13.6
Bauhaus H;	2023	Sports	519	17	10	519	17	9

Table 5. Article overall quality evaluation form.

Author	Year	Total offset risk assessment	
Kevin Hanson	2024		Medium-risk bias
Avari P	2023		Medium-risk bias
Toyota M	2021		Medium-risk bias
Narasaki Y	2024		Low-risk bias
Villard O	2022		Low-risk bias
Matzka M	2024		No information
Villa-Tamayo	2024		Medium-risk bias

Continued

Bauhaus H	2023		High-risk bias
Olafsdottir AF	2022		High-risk bias
Eichenlaub M	2025		Medium-risk bias
Pleus S	2022		High-risk bias

Green: Low-risk bias; Yellow: Medium-risk bias; Red: High-risk bias; Black: Extremely high risk bias; Circle: No information.

2.6. Data Collection and Statistical Analysis

All included studies used consistent measurement tools, enabling a meta-analysis of combined quantitative data. The mean and standard deviation of the scores on the humanistic care ability scale in each study were summarized using Stata SE.14, and presented using weighted mean difference (WMD) effect sizes and 95% confidence intervals (CI). The Cochrane Q test and I^2 statistics were utilized with I^2 values of 25%, 50%, and 75%, indicating low, moderate, and high heterogeneity, respectively [20]. When $I^2 > 50\%$, and $p < 0.05$, a random-effects model was used.

3. Results

3.1. Overall Results

Results, as shown in Figure 2, indicate that among the 11 studies that could affect continuous glucose monitoring (CGM) outcomes, the analysis produced χ^2: 3438.01, $I^2 = 99.7\%$, $P = 0.266 > 0.05$. There were no significant differences in the effects of influencing factors between the groups.

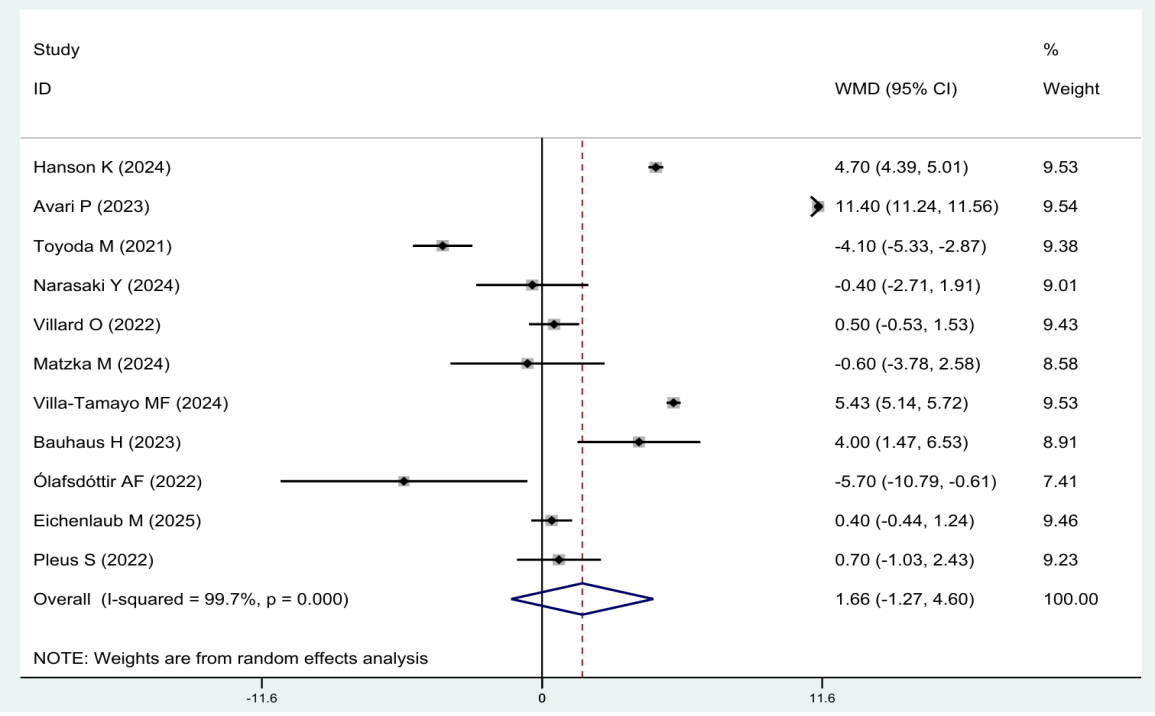

Figure 2. Forest plot of factors affecting continuous glucose monitoring.

3.2. Subgroup Analysis of the Study

3.2.1. Product Performance Result

As shown in Figure 3, indicate that among the 11 studies that could affect continuous glucose monitoring (CGM) outcomes, the analysis yielded χ^2: 2046.12, I^2 = 99.8%, P = 0.269 > 0.05. There were no significant differences in the effects of influencing factors between the groups.

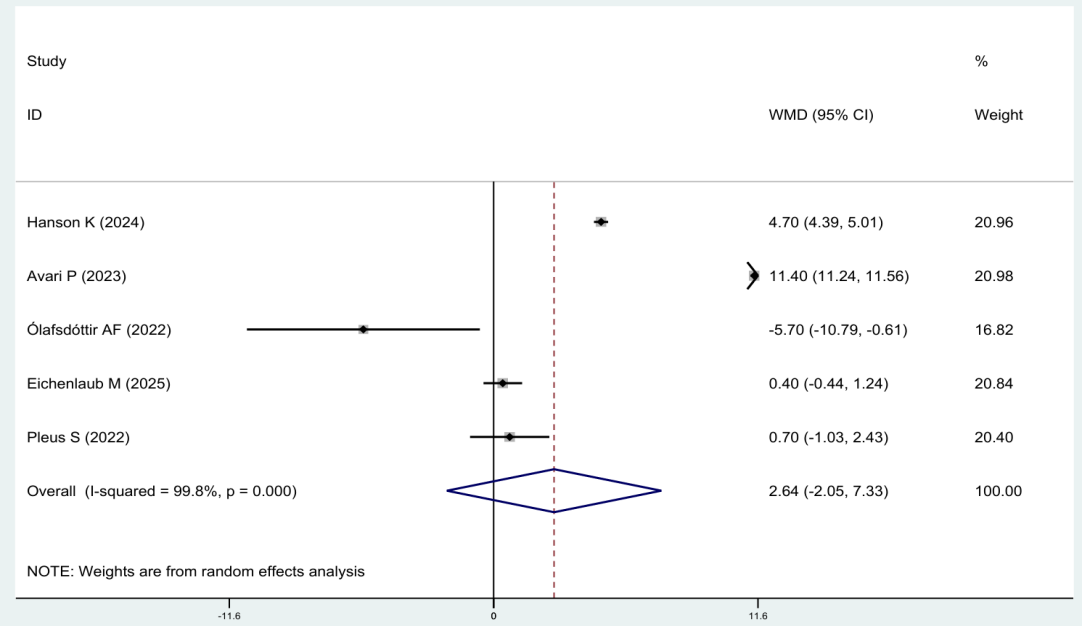

Figure 3. Subgroup analysis of influencing factors of product performance in continuous ambulatory blood glucose monitoring results forest plot.

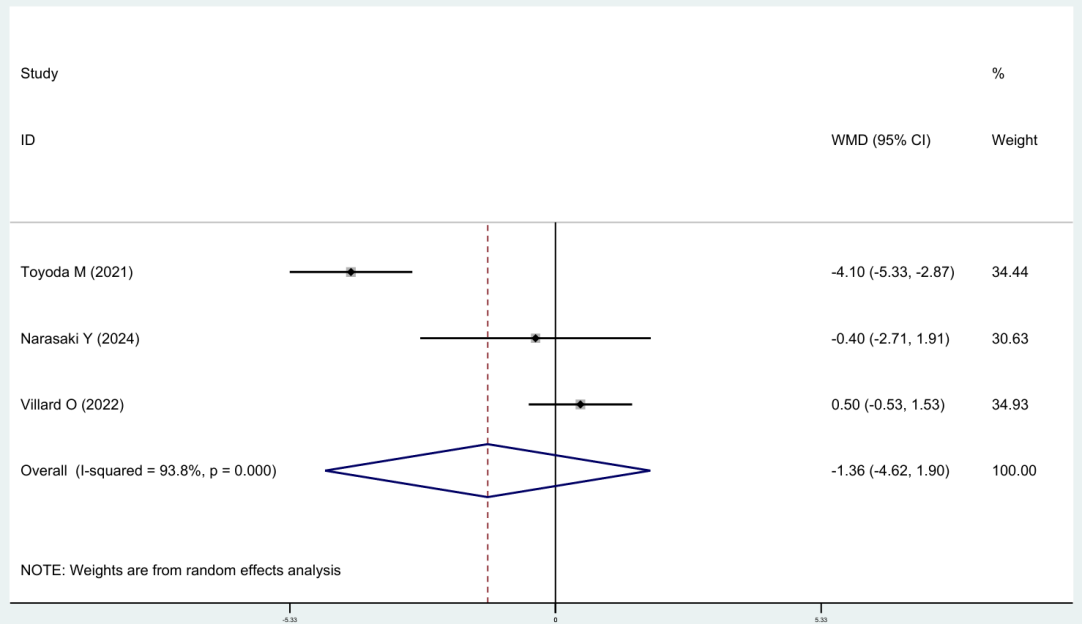

Figure 4. Subgroup analysis of influencing factors of hemodialysis based on continuous ambulatory glucose monitoring results, forest plot.

3.2.2. Hemodialysis

As a result, for example: Figure 4, among the 11 studies that might affect the results of continuous dynamic glucose monitoring (CGM), the analysis results showed that χ^2: 30.7, I^2 = 93.8%, P = 0.413 > 0.05. There is no difference in the effect of each influencing factor between groups.

3.2.3. Exercise Result

As shown in Figure 4, indicate that among the 11 studies that could affect continuous glucose monitoring (CGM) outcomes, the analysis yielded χ^2: 0.62, I^2 = 0.0%, P = 0.432 > 0.05 (see in Figure 5). There were no significant differences in the effects of influencing factors between the groups.

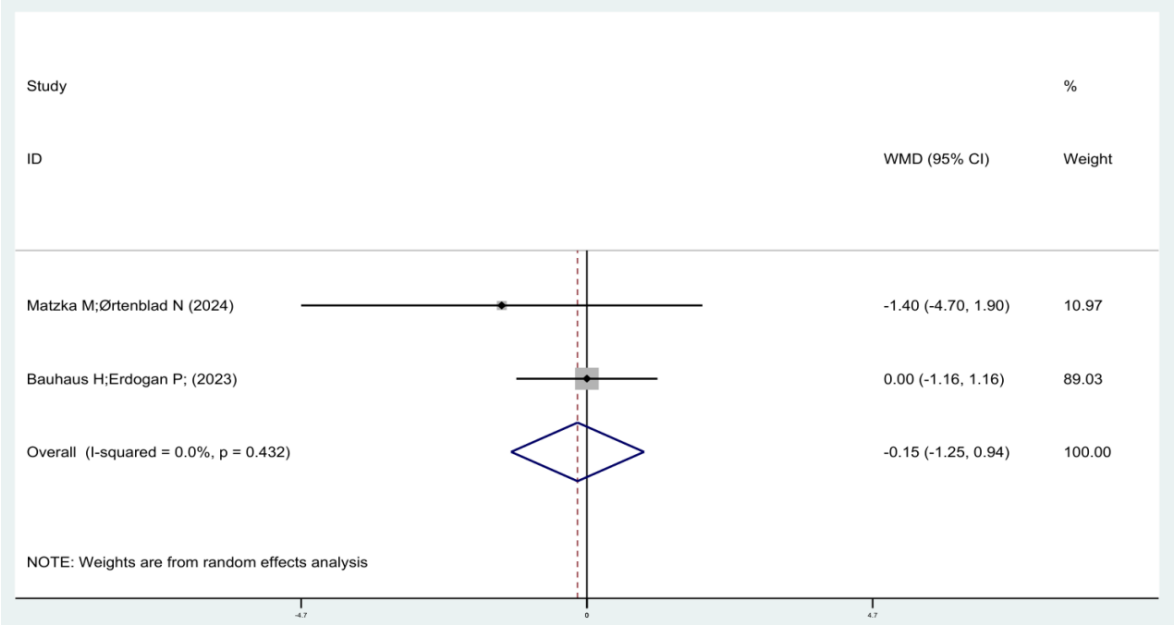

Figure 5. Subgroup analysis of exercise influencing factors in continuous ambulatory glucose monitoring results Forest plot.

4. Discussion

4.1. Product Performance

With continuous technological advancements, the methods for continuous glucose monitoring (CGM) have been consistently updated and developed in numerous studies. These advancements have reduced interfering factors, improved monitoring signals and sensitivity, and even allowed for stable and accurate blood glucose readings in critically ill patients experiencing hypoxia. In recent years, many manufacturers have been committed to product improvements, calibration, algorithms, and technological updates, making CGM more precise and reliable [21]-[27]. This has facilitated easier self-management of blood glucose for patients, reducing pain and anxiety and increasing patient compliance with self-management. The stability of CGM provides clinical value for healthcare providers monitoring blood glucose in different patients, improving work efficiency and

effectively preventing hypoglycemia [28]. It also offers healthcare professionals a reliable basis for clinically guiding patients in dietary and medication management [29].

4.2. Hemodialysis

Diabetes is a leading cause of end-stage renal failure. Concerns have been raised about whether continuous glucose monitoring (CGM) results might be inaccurate in hemodialysis patients. However, analysis indicates that CGM accuracy is not impacted in these patients. In hemodialysis patients, CGM can effectively prevent adverse events such as hypoglycemia [30]. It also aids in guiding insulin medication during dialysis, providing valuable insights. CGM can be a significant benefit for blood glucose management in hemodialysis patients [31] [32].

4.3. Exercise

Regarding exercise, there is some debate about whether it interferes with continuous glucose monitoring (CGM) results. Some studies suggest that exercise may impact CGM results, but this remains controversial [33] [34]. From the analysis, exercise does not appear to significantly affect the accuracy of the results. This could be related to product performance, as research indicates that the Dexcom G6 product shows better accuracy during exercise [35].

5. Conclusion

In summary, product performance, hemodialysis, and exercise do not excessively impact the accuracy of continuous glucose monitoring (CGM) results. Although some studies suggest that peritoneal dialysis, cardiac surgery, surgical operations, radiofrequency ablation, and high-altitude living environments can affect CGM results, the research is limited [7] [36]-[39]. There are no recent RCTs or observational studies to serve as the best evidence. In the future, we hope more similar studies will be published to provide a foundation for accurately assessing patient blood glucose levels in clinical settings.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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