



Safety and efficacy of glucagon-like peptide 1 receptor agonists in solid organ transplant recipients with diabetes mellitus: a systematic review and meta-analysis

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There is limited evidence to support the use of glucagon-like peptide-1 receptor agonists (GLP-1RAs) in solid organ transplants (SOTs). This systematic review and meta-analysis aimed to assess the safety and efficacy of GLP-1RAs in this population. PubMed, Embase, and Cochrane databases were a thorough literature search until July 2024 for SOTs with pre- and posttransplant diabetes mellitus (DM). Hemoglobin A1c (HbA1c), weight, and body mass index (BMI) were the primary outcomes. We estimated odds ratios and standardized mean difference (SMD) or mean difference (MD) with 95% confidence interval (CI) for dichotomous and continuous outcomes, respectively. I^2 statistics measured heterogeneity. GLP-1RAs were administered to 806 subjects (99.8%) in 16 trials. Median follow-up was 12 months (interquartile range, 1–49 months). The mean age was 57.05 ± 10.24 years, with 64.6% male patients. HbA1c levels (MD, -0.61% [95% CI, -0.82 to -0.40]; $p < 0.01$, $I^2 = 72\%$), weight, and BMI were statistically significantly reduced. Estimated glomerular filtration rate (eGFR; SMD, -0.38 mL/min/1.73 m² [95% CI, -1.01 to 0.25]; $p = 0.24$, $I^2 = 0\%$), creatinine, and blood pressure did not change significantly. Additionally, total daily insulin dosage, lipid profile, fasting plasma glucose, and urine albumin-to-creatinine ratio and tacrolimus levels (MD, -0.40 ng/mL [95% CI, -0.85 to 0.05]; $p = 0.08$, $I^2 = 42\%$) did not yield statistically significant. GLP-1RAs caused increased nausea and vomiting (13.9%), urinary tract infections (21.1%), and drug discontinuation (13.4%). In SOT recipients, GLP-1RAs significantly reduced HbA1c, weight, and BMI without significantly altering tacrolimus trough levels, eGFR, creatinine, or cardiovascular outcomes. Gastrointestinal side effects were the most common adverse events.

Keywords: Glucagon-like peptide-1 receptor agonists, Hypoglycemic agents, Organ transplantation, Postoperative complications, Type 2 diabetes mellitus

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Introduction

Diabetes mellitus (DM) is a very common and serious disease in many solid organ transplant (SOT) patients, including the built-in DM (preexisting DM) and those who develop after transplantation. Posttransplant DM (PTDM) affects about 10% to 40% of transplant recipients; the number depends on various reasons such as organ type, immunosuppressant drugs, and patient characteristics [1–3]. PTDM is linked to increased cardiovascular-related morbidity/mortality, lower rates of graft survival, and elevated mortality; such management thus ranks as one critical component of any care plan for the transplanted livers and kidneys [4–8].

The management of PTDM poses a challenge as it requires the presence of characteristics that are unique physiologically and pharmacologically in transplant recipients. There are problems with using traditional antidiabetic therapies as they carry certain risks such as the development of hypoglycemia, weight gain, and also interactions with immunosuppressive agents [9–11]. In the above-mentioned conditions, glucagon-like peptide-1 receptor agonists (GLP-1RAs) have begun to provide new effective ways of treatment. The crucial role of these substances is that they promote glycemic control by glucose-dependent insulin secretion, inhibit glucagon, delay the speed of gastric emptying, and consequently reduce appetite, which is a source of the most common side effect, which is hypoglycemia, and by the way stimulates weight loss [9,12]. These impacts are especially critical for SOT patients because weight gain and associated metabolic complications are frequent in them after transplantation [9,13].

Clinical trials, such as LEADER, SUSTAIN-6, and REWIND, have shown that GLP-1RAs reduce major adverse cardiovascular events and provide renal protection in patients with T2DM. These data suggest that GLP-1RAs may also benefit transplant recipients, but there is little clinical proof for the case of patients who received organ transplants [14–16]. On the other hand, retrospective studies and meta-analyses revealed that the use of GLP-1RAs resulted in improved glycemic control and body weight loss in kidney transplant recipients (KTR) with no major effects on tacrolimus pharmacokinetics and transplant outcomes on the short term [5,17]. Nevertheless, the issue about the long-lasting effect of GLP-1RAs on graft function, their

tolerability, and possible drug-drug interactions with calcineurin inhibitors (CNIs) and other immunosuppressive agents is still open.

An important consideration in the combination is the interaction of GLP-1RAs with immunosuppressive agents, specifically CNIs and corticosteroids, and these may have a bearing on glycemic control, weight, and gastrointestinal side effects [18,19]. Indeed, some data are available suggesting that GLP-1RAs do not influence tacrolimus levels substantially; however, inconsistencies in study administration timing and dosage may be partially responsible for inconsistent findings. GLP-1RAs are also known to induce gastrointestinal symptoms such as nausea and diarrhea, which may be worsened during immunosuppressive treatment in recipients after SOT and therefore might limit the long-term use of these drugs [20].

Other unknowns include GLP-1RAs' long-term impact on graft function and survival. GLP-1RAs protect the kidney in diabetic renal disease patients but can influence kidney graft function in transplant recipients. These drugs' effects on liver and heart transplant recipients are infrequently reported, making it hard to generalize their benefits. Further studies are required to clarify the timing of immunosuppressive medication initiation posttransplant and its effect on glycemic and weight outcomes. In addition, there is no clear documentation in the literature regarding the outcomes of rejection with GLP-1RAs, making them unsafe for this use [12,21].

This systematic review with meta-analysis assesses the safety and efficacy of GLP-1RAs in SOT recipients with DM, in terms of glycemic control, weight changes, and cardiovascular outcomes. It examines side effects such as gastrointestinal disorders and hypoglycemia and interactions with immunosuppressants. The key outcomes will be used to guide clinical decisions and further research in the management of DM for these patients.

Methods

This systematic review and meta-analysis was performed and reported in accordance with the Cochrane Collaboration Handbook for Systematic Review of Interventions and the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) Statement guidelines [22].

Eligibility criteria

Inclusion in this meta-analysis was restricted to studies that met all the following eligibility criteria: (1) observational studies, clinical trials, and case series reports; (2) evaluating the safety and efficacy of GLP-1RAs after SOT (kidney, liver, heart, lungs, and pancreas) in adults >18 years of age; (3) regardless of pre- or post-type 2 DM (T2DM); (4) reporting at least one of the clinical outcomes of interest; (5) regardless of follow-up period.

We exclude studies with (1) conference abstracts, case reports, editorials, reviews, and studies without original data; (2) no outcome of interest; (3) studies that reported on recipients other than SOT; and (4) exclude studies with duplicate data, identified as studies published from the same author or the same institution in an overlapping period. In the case of duplicate data, only the studies with the latest year that contained the variable of interest were selected. There were no restrictions concerning the date and language.

Relevant studies were identified by two independent reviewers (MU and CL), with discrepancy resolved by arbitration (XC).

Search strategy and data extraction

The PubMed, Embase, and Cochrane databases were systematically searched until July 2024 ([Appendix 1](#)). The search strategy employed the following MeSH search terms: (organ transplantation OR transplant) AND (glucagon-like peptide-1 receptor agonist OR GLP-1-RAs OR albiglutide OR semaglutide OR exenatide OR dulaglutide OR liraglutide OR lixisenatide). Relevant studies' reference lists were screened as well. Data were independently extracted by two authors (MU and YZ) according to pre-defined search criteria. The WebPlotDigitiser tool (version 4.6, Ankit Rohatgi) was used when relevant data were exclusively presented in graphical format, in accordance with the guidelines outlined in the Cochrane Handbook for Systematic Reviews of Interventions [22,23]. Data for efficacy endpoints were preferably extracted from the efficacy estimand analysis, which considered full treatment adherence and excluded data following the use of rescue therapy whenever available [22].

Disagreements between two authors were resolved by a third reviewer (HY). The meta-analysis protocol (CRD4202

4594895) was registered with PROSPERO in September 2024.

Endpoints

Our primary endpoints of this study were the mean changes from baseline in glycated hemoglobin (hemoglobin A1c, HbA1c; expressed as a percentage), body weight (in kilograms), and body mass index (BMI, in kg/m²). Secondary efficacy endpoints included markers of graft function—namely estimated glomerular filtration rate (eGFR), urine albumin-to-creatinine ratio (UACR), and serum creatinine—as well as metabolic outcomes, including fasting plasma glucose (FPG), total daily insulin dosage (TDD), total cholesterol, high-density lipoprotein (HDL) and low-density lipoprotein (LDL) cholesterol, and systolic (SBP) and diastolic blood pressure (DBP). Cardiovascular events and mortality were also assessed as secondary outcomes.

The inclusion of both eGFR and creatinine was deliberate, as these complementary measures provide a more comprehensive evaluation of renal function. eGFR is a widely accepted, standardized estimate of glomerular filtration capacity, while creatinine reflects the body's ability to clear a metabolic byproduct and is commonly used in clinical settings. Together, these parameters enhance the robustness of the renal outcome assessment, particularly in transplant recipients.

Safety endpoints included the change in tacrolimus levels from baseline, as well as the occurrence of adverse events and allograft rejection episodes.

Quality assessment

The Cochrane tool for assessing risk of bias in observational and case series studies (RoB1) was used for quality assessment of studies [24]. The risk of bias evaluation was performed independently by two authors (MU and KX), with disagreements resolved by consensus. Publication bias was assessed with funnel-plot analysis and Egger's test of all endpoints to evaluate the symmetric distribution of trials with similar weights.

Statistical analysis

This meta-analysis was conducted in accordance with the

Cochrane Collaboration's recommendations and followed the PRISMA guidelines [25,26]. Odds ratios with a 95% confidence interval (CI) are used to articulate the differences in effects for dichotomous outcomes. For continuous efficacy and safety endpoints, mean changes from baseline with corresponding standard deviations (SDs) were calculated by subtracting final means from baseline values. Mean differences (MDs) were used when outcomes shared the same units, while standardized MDs (SMDs) with 95% CIs were applied otherwise. To estimate the SD of the mean change, we used a conservative correlation coefficient of 0.5, as recommended in the literature [27]. The inverse-variance method was applied for continuous outcomes. A study involved a two-trial group of distinct GLP-1RAs, which were regarded as separate entities [28].

Two studies were missing SDs; pooled SDs were calculated using the following formula.

$$S_p = \sqrt{\frac{\sum (n_i - 1) s_i^2}{\sum (n_i - 1)}}$$

Each safety binary endpoint was evaluated based on events and the total sample size.

In placebo-controlled trials, we extracted the measurement results of the primary and secondary endpoints exclusively from the group receiving the active drug, excluding data from the placebo group.

Heterogeneity was assessed using Cochran's Q test, I^2 statistics, and visual inspection of the forest plots. A p-value <0.1, an I^2 exceeding 50% = moderate and I^2 >75% = high, and visually diverse patterns were deemed significant markers of heterogeneity. The restricted maximum-likelihood method was applied for MDs, while the DerSimonian-Laird estimator was used for SMDs. The logit transformation is suitable for binary endpoints when observed proportions <0.2 or >0.8. The Freeman-Tukey double arcsine transformation is used for minimal or extreme proportions (i.e., 0 or 1). The random-effects method was used. Subgroup analyses were conducted for follow-up periods of 6–12 months, 12 months, and above 18 months.

Regarding heterogeneity, we conducted leave-one-out sensitivity analyses to ascertain that the results were not contingent upon any single study. Funnel plots and Egger's test were used to assess publication bias. Furthermore, to augment the rigor of our analysis, we performed an additional

sensitivity analysis by excluding studies with a sample size of fewer than 15 patients. We also performed the analysis, removing Singh et al. [28] because of the pooled mean SD. In all studies, a p-value less than 0.05 was deemed statistically significant. Statistical analyses were conducted using R version 4.4.1 (R Foundation for Statistical Computing).

Results

Study selection and baseline characteristics

Fig. 1 shows the search strategy yielded in 3,593 studies. After removing duplicates and screening titles and abstracts, 86 full-text articles were assessed for eligibility, resulting in the inclusion of 16 studies comprising 1,218 participants. Of these, 808 patients received treatment, with 806 (99.8%) receiving GLP-1RAs. The mean age across trials was 57.05 ± 10.24 years.

We analyzed 12 retrospective cohort studies without control groups [12,20,29–38], three with control groups [39–41], and one with a comparison group by Singh et al. [28]. Two distinct groups received GLP-1RAs (dulaglutide vs. liraglutide), which were reported as two separate arms [28]. Four studies reported on SOTs: Dotan et al. [39] reported kidney, liver, lungs, and heart; Singh et al. [28] reported kidney, liver, liver-kidney, and heart; Sweiss et al. [31] reported kidney, kidney-liver, lungs, liver, and kidney-pancreas; and Thangavelu et al. [20] reported kidney, liver, and heart. Eleven studies reported kidney transplantation [12,29,32–38,40,41]. One study reports on heart transplantation [30].

Nearly all transplant recipients (99.4%) had DM, with only five patients (0.6%) without DM, reported by Yugueros González et al. [38]. Among the diabetic cohort, 64.0% had T2DM, and 36.0% had PTDM.

Immunosuppressive therapy was detailed in 14 studies [12,20,28–35,38–41], with tacrolimus used in 65.3% of patients and corticosteroids 42.0%. Among the 806 patients treated with GLP-1RAs, dulaglutide was the most commonly prescribed (310 patients, 38.5%), getting 0.5 to 1.5 mg weekly. After liraglutide, semaglutide was prescribed to 219 patients (27.2%). Eight patients (1.0%) received exenatide. The median follow-up duration was 12.0 months (interquartile range, 1–49 months), with a mean follow-up of 15.9 ± 10.93 months, as shown in Table 1.

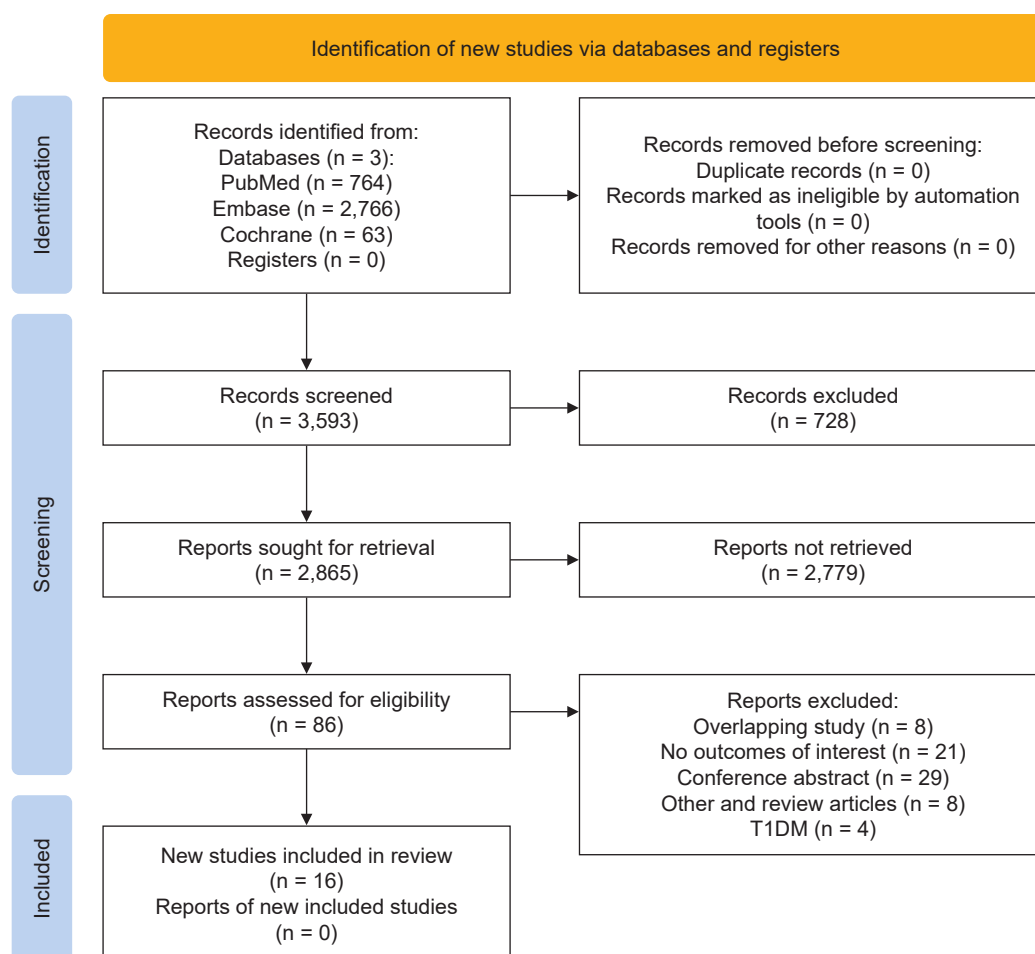


Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analysis) flow diagram of study screening and selection.

T1DM, type 1 diabetes mellitus.

Efficacy of primary and co-primary glucagon-like peptide-1 receptor agonists in glycemic and weight

Hemoglobin A1c

The difference in HbA1c before and after GLP-1RA treatment was reported in 15 trials involving 788 patients [20,28–41]. Across these studies, the MD in HbA1c ranged from -2.93% to 0.69%. Overall, a significant reduction was observed, with a pooled MD of -0.61% (95% CI, -0.82 to -0.40; $p < 0.01$, $I^2 = 72\%$) (Fig. 2A). The studies by Vigara et al. [32], Dotan et al. [39], and Sweiss et al. [31] contributed most to the final estimate.

Subgroup analysis based on transplant organ type showed consistent reductions in HbA1c. In SOT recipients, the MD was -0.62% (95% CI, -0.81 to -0.43; $p < 0.01$, $I^2 = 5\%$)

[20,28,31,39], while in KTRs, the MD was -0.63% (95% CI, -0.96 to -0.29; $p < 0.01$, $I^2 = 80\%$) [29,32–38,40,41] and heart transplant recipients showed the largest reduction, with an MD of -0.90% (95% CI, -1.33 to -0.47) [30] as shown in [Supplementary Fig. 1](#) (available online).

When stratified by follow-up duration, GLP-1RAs significantly reduced HbA1c at all time points. At <12 months, the MD was -0.60% (95% CI, -0.88 to -0.33; $p < 0.01$, $I^2 = 71\%$); at 12 months, -0.61% (95% CI, -0.80 to -0.43; $p < 0.01$, $I^2 = 57\%$); and at >18 months, -0.69% (95% CI, -1.21 to -0.17; $p < 0.01$, $I^2 = 80\%$), with persistently high heterogeneity at longer durations ([Supplementary Fig. 2](#), available online).

We also performed leave-one-out analysis; omitting Kim et al. [37] had the most significant effect on heterogeneity reduction ([Supplementary Fig. 3](#), available online).

Table 1. Baseline characteristics of studies included in meta-analysis

Study	Dotan et al. [39] (2024)	Mahmoud et al. [40] (2023)	Mahzari et al. [29] (2021)	Sammour et al. [30] (2021)	Singh et al. (2020) [28]	Swiss et al. [31] (2022)	Thangavelu et al. [20] (2020)	Vigara et al. [32] (2024)	Vigara et al. [33] (2022)	Liou et al. [34] (2018)	Kukla et al. [35] (2020)	Mallik et al. [36] (2023)	Kim et al. [37] (2021)	Yugueros González et al. [38] (2021)	Pinelli et al. [12] (2013)	Sato et al. [41] (2023)
Study type	Retrospec- tive	Retrospec- tive	Retrospec- tive cohort	Retrospec- tive cohort	Retrospective with compar- ison group	Retrospec- tive	Retrospec- tive	Multicenter retrospec- tive cohort	Retrospec- tive cohort	Retrospec- tive cohort	Retrospec- tive cohort	Retrospec- tive cohort	Retrospec- tive cohort	Retrospec- tive cohort	Retrospec- tive cohort	Retrospec- tive cohort with a control group
Country	Israel	Kuwait	Saudi Arabia	USA	USA	USA	USA	Spain	Spain	Taiwan	USA	UK	South Korea	USA	USA	USA
No. of patients	169 ^a	41 ^c	39	21	88 ^d	118	19	96 ^b	40 ^f	7	17	23 ⁱ	37	15 ^k	5	73
Transplanted organ	SOT ^b	Kidney	Kidney	Heart	SOT ^e	SOT ^f	SOT ^g	Kidney	Kidney	Kidney	Kidney	Kidney	Kidney	Kidney	Kidney	Kidney
GLP-1RAs (%)	LIR 34 DU 46 SEM 20	DU	SEM	SEM	DU/LIR	LIR 31 DU 38 SEM 27 EXE 4	LIR 53 DU 26 EXE 11 SEM 10	SEM 66.7 LIR 20.8 DU 12.5	SEM 48 LIR 32 DU 20	LIR	LIR 82 DU 12 EXE 6	DU 74 LIR 26	DU	SEM 54 LIR 3 DU 15	LIR	NA
T2DM/PTDM (%)	82/18	73/27	54/46	NA/100	NA/80	68/NA	84/16	56/44	60/40	NA	65/18	NA	T2DM	27/40	PTDM	T2DM
Dosage	NA	1.5 mg subcutaneous weekly	NA	Lowest dose with no up-titration	DU 0.75 mg/wk maximum 1.5 mg/wk LIR 0.6 mg/day subcutaneously optimized to 1.8 mg/day	NA	Titrated GLP-1-RA dose as recommended protocol	GLP-1RAs subcutaneously administered	58% reached the maximum recommended dose of the drug	Start at 0.6 mg/day optimized to 1.8 mg/day	LIR 0.6–1.8 mg/day DU 0.5–0.75 mg/wk EXE 2 mg/wk	NA	0.75 mg/wk (46%) and 1.5 mg/wk (54%)	NA	Start at 0.6 mg/day optimized to 1.8 mg/day	NA
Male sex, n (%)	116 (69)	23 (73)	29 (74)	14 (67)	43 (68)/18 (72)	30 (41)	12 (63.2)	54 (56.2)	21 (52.5)	NA	14 (82.4)	15 (65.2)	18 (48.6)	10 (66.7)	3 (60)	102 (69.9)
Age (yr) ^m	58.3 ± 11.0	53	54 ± 9	59.4 ± 9.5	58 ± 11/57 ± 10.25	58 ± 11/57 ± 10.25	62 ± 5.75	61.6 ± 9.7	62.8	NA	51.8 ± 16.1	56.5	54.8 ± 8.5	54 ± 8.9	55.4 ± 8.2	57.4 ± 10.3
BMI (kg/m ²) ^m	31.2 ± 4.3	33.6	NA	36 ± 5.1	32.8/36.8	32 ± 6	35.98 ± 4.96	35.8 ± 4.8	35.8 ± 5.4	29.4 ± 2.8	34.1 ± 3.9	NA	25.7 ± 3.4	31.2 ± 4.3	30.1 ± 6.2	25.1 ± 3.5
Hb1Ac (%) ^m	7.8 ± 1.4	8	8.4 ± 1.3	7.5 ± 0.35	7.5/7.5	8 ± 0.5	8.0 ± 1.55	7.3 ± 1.2	7.5 ± 0.9	10.0 ± 1.6	7.4 ± 1.2	NA	7.0 ± 0.9	6.9 ± 1.9	NA	7.1 ± 1.1
eGFR (mL/min/1.73 m ²) ^m	61 ± 24	68.4	72.0 ± 19.3	55 ± 5	48/42.48	55 ± 5	NA	47.3 ± 18.3	46.1 ± 15.2	67.7 ± 18.7	53.0 ± 14.7	NA	71.7 ± 18.5	NA	87.6 ± 19.8	44.4 ± 13.6
Creatinine (mg/dL) ^m	1.11 (0.97–1.52)	NA	90.0 ± 32.6	1.3 (1.1–1.6)	1.6/1.8	1.20 ± 0.13	NA	1.5 ± 0.2	NA	1.2 ± 0.4	1.4 ± 0.4	NA	1.1 ± 0.3	1.3 ± 0.5	1.0 ± 0.2	NA
UACR (mg/dL) ^m	33 ± 43.25	4.09	6.85 ± 37.74	NA	NA	NA	NA	128.0 ± 134.25	NA	NA	NA	NA	NA	NA	NA	NA
Total daily insulin dose (units) ^m	NA	NA	NA	88 ± 22.13	23/50	26.5 ± 16.5	60 ± 62.5	53.9 ± 4.7	49 ± 30	NA	63 ± 52	NA	25 ± 12	NA	NA	NA
OAD, n (%)																
Metformin	76 (45)	34	19 (49)	8 (38)	NA	28 (25)	3		5 (13)		8 (47)		34 (92)			
Sulphonilurea	5 (3)	4	8 (21)	5 (24)	NA	2 (2)	2		1 (3)		2 (12)		19 (51)			
Pioglitazone	1 (0.6)	NA	NA	NA	NA	NA	NA	NA	NA	NA	1 (6)	NA	NA	NA	NA	NA
DP4i	10 (6)	0	8 (21)	2 (9)	NA	2 (2)	3		NA		NA		NA			
Insulin	112 (66)	33	33 (85)	NA	44/46	70 (59)	7		NA		NA		NA			

(Continued from the previous page)

Table 1. Continued

Study	Dotan et al. [39] (2024)	Mahmoud et al. [40] (2023)	Mahzari et al. [29] (2024)	Sammour et al. [30] (2021)	Singh et al. (2020) [28]	Swiss et al. [31] (2022)	Thangavelu et al. [20] (2020)	Vigara et al. [32] (2024)	Vigara et al. [33] (2022)	Liou et al. [34] (2018)	Kukla et al. [35] (2020)	Mallik et al. [36] (2023)	Kim et al. [37] (2021)	Yugueros González et al. [38] (2021)	Pinelli et al. [12] (2013)	Sato et al. [41] (2023)
Immunosuppressive drug use, n (%)																
Tacrolimus	CNI, 160 (95)	30	37 (95)	21 (100)	CNI, 81/64 ^m	117 (99)	18	89 (92.7)	40 (100)	7 (100)	16 (94)			13 (100)	5 (100)	CNIs 146 (100)
Cyclosporin	NA	9	1	NA		1 (0.8)	1	3 (3.1)	NA	NA	0			NA	NA	146 (100)
Everolimus	NA	NA	NA	SRL 12 (57)		SRL, 1 (0.8)	SRL 1	4 (4.2)	1 (3)	NA	1 (6)	NA	NA	NA	NA	146 (100)
Mycophenolate	NA	NA	39 (100)	8 (38)		95 (80.5)	10	41 (42.7)	38 (95)	NA	15 (88)			NA	NA	
Corticosteroids	165 (98)	NA	38 (98)	7 (33)		90 (76.3)	6	90 (93.8)	38 (95)	NA	11 (65)			NA	4 (80)	
Follow-up (mo) ^m	17	12	18	9.1	24	12	12	12	12	19.4 ± 7.6	12	26.5 ± 16.5	6	12	1	49.4

BMI, body mass index; CNI, calcineurin inhibitor; DM, diabetes mellitus; DP4i, dipeptidyl peptidase IV inhibitor; DU, dulaglutide; eGFR, estimated glomerular filtration rate; EXE, exenatide; GLP1-RA, glucagon-like peptide-1 receptor agonist; HbA1c, hemoglobin A1c; LIR, liraglutide; NA, no available data; OAD, oral antidiabetic drug; PTDM, posttransplant diabetes mellitus; SEM, semaglutide; SOT, solid organ transplant; SRL, sirolimus; T2DM, type 2 diabetes mellitus; UACR, urine albumin-to-creatinine ratio.
^a338 in total: 169 received GLP1-RAs; 169 controls. ^bSOT: kidney, liver, lung, heart. ^c209 in total: 41 received GLP1-RA, 98 received sodium-glucose cotransporter 2 inhibitor (SGLT2i), 70 controls. ^dDU 63/LIR 25. ^eSOT: kidney, liver, liver-kidney, heart. ^fKidney, kidney-liver, lung, liver, kidney-pancreas. ^gKidney, liver, heart. ^h96 started GLP1-RA then decreased to 84 at 6 months and 61 at 12 months. ⁱTotal 50 included then 40 received GLP1-RAs at 6 months then decreased to 26 at 12 months. ^j23 received GLP1-RAs at 6 months then decreased to 19 at 12 months and 12 at 24 months. ^k15 in total: 13 received GLP1-RAs, 2 received SGLT2i. Mean or median. ^l81% in the dulaglutide group and 64% in the liraglutide group.

Weight and body mass index

The co-primary outcome, mean change in body weight from baseline, demonstrated a significant reduction, with an MD of -3.39 kg (95% CI, -4.54 to -2.24; $p < 0.01$, $I^2 = 30\%$) (Fig. 2B), based on data from 14 studies involving 636 patients [12,20,28-39].

Subgroup analysis stratified by organ transplant type and different follow-up periods as shown in Supplementary Fig. 4A (available online). The analysis of SOTs [20,28,31,39], KTRs [12,29,32-38], and heart transplant [30] showed a significant reduction in weight, with an MD of -2.56 kg (95% CI, -4.06 to -1.06; $p < 0.01$, $I^2 = 37\%$), -3.91 kg (95% CI, -5.45 to -2.37; $p < 0.01$, $I^2 = 0\%$), and -12.33 kg (95% CI, -19.63 to -5.03), respectively. Treatment follow-up period revealed GLP-1RAs significantly reduced weight in both short-term (<12 months) treatment (MD, -3.51 kg [95% CI, -4.72 to -2.30]; $p < 0.01$, $I^2 = 18\%$) and long-term treatment (at 12 months: MD, -2.95 kg [95% CI, -3.99 to -1.90]; $p < 0.01$, $I^2 = 12\%$; at >18 months: MD, -4.48 kg [95% CI, -6.49 to -2.48]; $p < 0.01$, $I^2 = 3\%$) (Supplementary Fig. 5, available online).

Due to less heterogeneity, we didn't perform leave-one-out analysis.

In terms of BMI, the overall analysis showed a significant reduction from baseline, with an MD of -1.44 kg/m² (95% CI, -2.02 to -0.87; $p < 0.01$, $I^2 = 64\%$) (Fig. 2C).

Subgroup analysis revealed reductions of -1.04 kg/m² in SOT recipients (95% CI, -1.61 to -0.47; $p < 0.01$, $I^2 = 46\%$) [20,28,31,39], -1.52 kg/m² in KTRs (95% CI, -2.36 to -0.67; $p < 0.01$, $I^2 = 60\%$) [32-36,38,40,41], and -4.00 kg/m² in heart transplant recipients (95% CI, -6.03 to -1.97) [30] as illustrated in Supplementary Fig. 4B (available online).

GLP-1RAs also significantly reduced BMI across time points. At <12 months, the MD was -1.13 kg/m² (95% CI, -1.57 to -0.69; $p < 0.01$, $I^2 = 41\%$). At 12 months, the reduction was -1.35 kg/m² (95% CI, -1.88 to -0.83; $p < 0.01$, $I^2 = 72\%$). However, at >18 months, the BMI change was -1.00 kg/m² (95% CI, -2.14 to 0.15; $p = 0.09$, $I^2 = 46\%$), which was not statistically significant, as shown in Supplementary Fig. 6 (available online).

Leave-one-out analysis showed that excluding Kukla et al. [35] reduced heterogeneity to $I^2 = 48\%$, as illustrated in Supplementary Fig. 7 (available online).

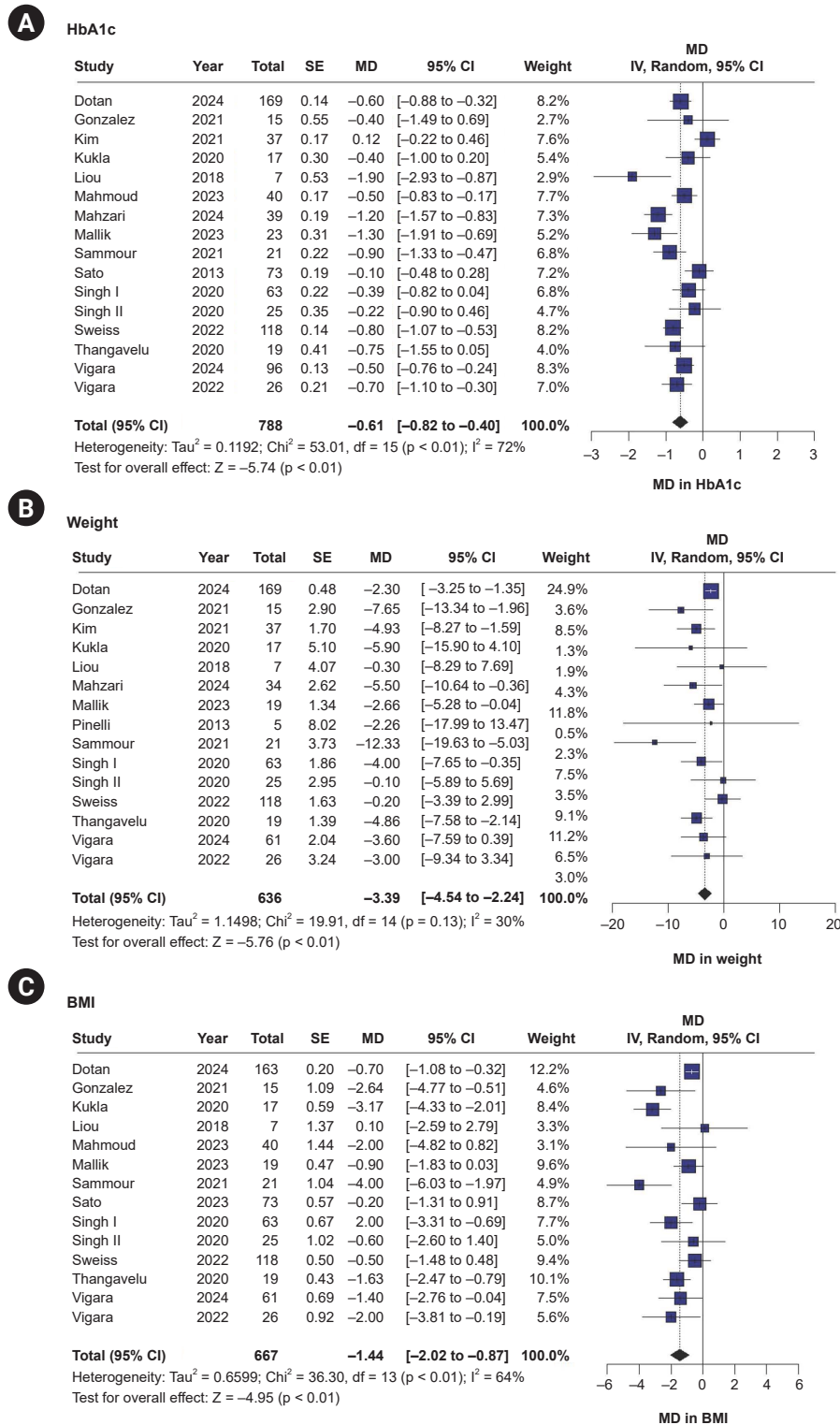


Figure 2. The effects of the administration of GLP-1RAs. Effects on (A) glycated hemoglobin (hemoglobin A1c, HbA1c) levels, (B) weight, and (C) body mass index (BMI). HbA1c presented on scale -3% to 3%, weight presented on scale -20 to 20 kg, and BMI presented on scale -6 to 6 kg/m². Studies are identified by the first author's name and year of publication.

CI, confidence interval; df, degree of freedom; GLP-1RAs, glucagon-like peptide-1 receptor agonists; IV, inverse variance; MD, mean difference; SE, standard error.

Secondary efficacy outcomes

Metabolic outcomes

Total daily dosage of insulin

A meta-analysis of nine studies with 393 patients using GLP-1RAs examined TDD [20,28,30–33,35–37]. The administration of GLP-1RAs significantly reduced the daily insulin dosage, resulting in MD of -6.37 units (95% CI, -10.92 to -1.83 ; $p < 0.01$, $I^2 = 76\%$) (Fig. 3A). In subgroup analysis, a shorter treatment period of <12 months resulted in no statistically significant reduction in insulin dose, while a 12-months MD of -3.26 units (95% CI, -5.93 to -0.58 ; $p = 0.02$, $I^2 = 35\%$) resulted in a significant reduction (Supplementary Fig. 8, available online).

A leave-one-out analysis was performed. Supplementary Fig. 8 shows that excluding Sammour et al. [30] reduced heterogeneity by 58%.

Blood pressure

GLP-1RAs had a nonsignificant effect on SBP in four studies, with an MD of -4.29 mmHg (95% CI, -9.70 to 1.12 ; $p = 0.12$, $I^2 = 50\%$) (Fig. 3B) [30,32,33,36]. DBP did not show a significant impact, with an MD of -0.56 mmHg (95% CI, -2.38 to 1.27 ; $p = 0.55$, $I^2 = 0\%$) (Fig. 3C) [30,32,33,35]. In subgroup analysis results at different follow-up periods. GLP-1RA had a significant effect on SBP at different time intervals, including <12 months, with an MD of -6.22 mmHg (95% CI, -11.28 to -1.16 ; $p = 0.02$, $I^2 = 53\%$) and -6.71 mmHg (95% CI, -10.22 to -3.19 ; $p < 0.01$, $I^2 = 34\%$) (Supplementary Fig. 9A, B; available online). However, DBP did not show a significant impact at both <12 -month and 12-month durations (Supplementary Fig. 9C, D, available online).

Total cholesterol

Seven trials with 332 participants administered GLP-1RAs reported outcomes for total cholesterol concerning the cholesterol profile. GLP-1RAs exhibit a significant reduction in total cholesterol levels compared to baseline, with an MD of -12.78 mg/dL (95% CI, -15.88 to -9.68 ; $p < 0.01$, $I^2 = 16\%$) (Fig. 3D). In the subgroup analysis depicted, there is a notable decrease in cholesterol throughout both <12 months and 12 months durations, with an MD of -11.79 mg/dL (95% CI, -17.09 to -6.48 ; $p < 0.01$, $I^2 = 0\%$) and -12.84 mg/dL (95% CI, -16.05 to -9.63 ; $p < 0.01$, $I^2 = 30\%$),

respectively (Supplementary Fig. 10, available online).

High- and low-density lipoprotein cholesterol

Difference in HDL and LDL levels before and after GLP-1RA treatment were reported in four trials (277 patients) for HDL [30,32,33,39] and five trials (296 patients) for LDL [20,30,32,33,39]. HDL and LDL levels showed statistically significant MD of -1.90 mg/dL (95% CI, -2.87 to -0.93 ; $p < 0.01$, $I^2 = 1\%$) (Fig. 3E) and -10.37 mg/dL (95% CI, -17.95 to -2.80 ; $p < 0.01$, $I^2 = 92\%$) (Fig. 3F). In subgroup analysis of <12 months, GLP-1RA demonstrated nonsignificant MD of -1.22 mg/dL (95% CI, -3.27 to 0.83 ; $p < 0.24$, $I^2 = 20\%$) and -4.36 mg/dL (95% CI, -12.87 to 4.15 ; $p = 0.32$, $I^2 = 95\%$), respectively. At 12 months, HDL and LDL significantly decreased by -1.90 mg/dL ($I^2 = 1\%$) and -10.82 mg/dL ($I^2 = 94\%$), as shown in Supplementary Fig. 11 (available online).

Efficacy of glucagon-like peptide-1 receptor agonists on graft function

Estimated glomerular filtration rate

Thirteen studies [12,20,28–36,40,41] involving 527 individuals compared eGFR before and after GLP-1RA treatment with an SMD of -0.38 mL/min/ 1.73 m² (95% CI, -1.01 to 0.25 ; $p = 0.24$, $I^2 = 0\%$) (Fig. 4A).

Subgroup analyses at different follow-up periods show that GLP-1RAs do not impair renal function. SMD values for <12 months, 12 months, and >18 months are -0.24 mL/min/ 1.73 m² (95% CI, -0.93 to 0.45 ; $p = 0.50$, $I^2 = 0\%$), 0.23 mL/min (1.73 m²; $p = 0.70$, $I^2 = 0\%$), and -0.65 mL/min (1.73 m²; $p = 0.10$, $I^2 = 0\%$), as shown in Supplementary Fig. 12 (available online).

Creatinine

This meta-analysis of nine studies with 320 patients found no significant effect on creatinine levels SMD 0.00 mmol/L (95% CI, -0.27 to 0.27 ; $p < 0.98$, $I^2 = 83\%$) (Fig. 4B) [12,28–31,34–36,38].

Subgroup analysis showed no significant outcomes for GLP-1RA across different follow-up periods (<12 months, 12 months, and >18 months). SMD 0.05 mmol/L (95% CI, -0.35 to 0.45 ; $p = 0.81$, $I^2 = 67\%$), -0.05 and -0.14 mmol/L (95% CI, -0.48 to 0.19 ; $p = 0.41$, $I^2 = 0\%$) (Supplementary Fig. 13, available online).

In leave-one-out analysis by omitting Sweiss et al. [31]

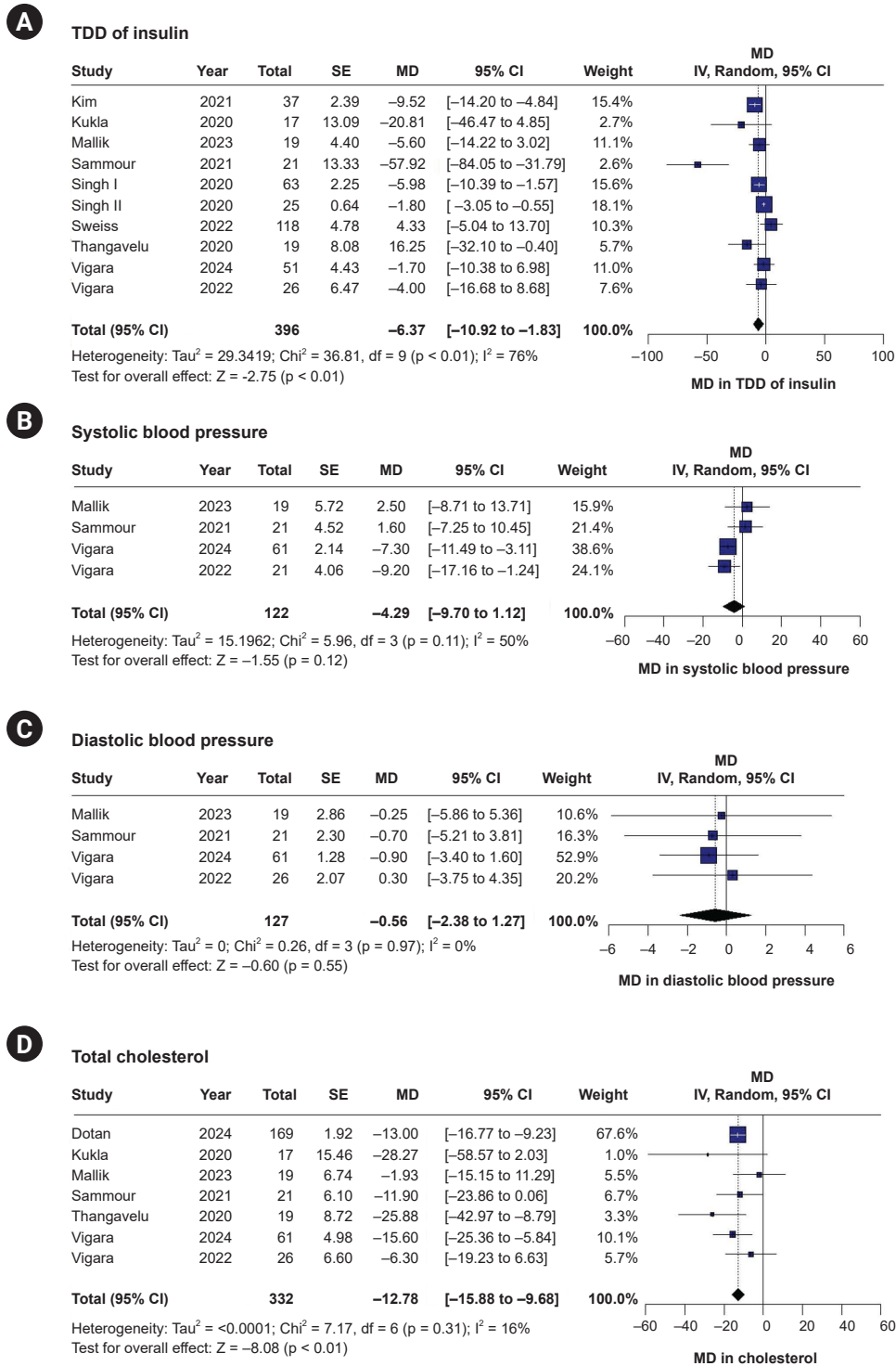


Figure 3. Forest plot of the effects of the administration of GLP-1RAs. Effects on (A) total daily dosage (TDD) of insulin (units), (B) systolic blood pressure (mmHg), (C) diastolic blood pressure (mmHg), (D) total cholesterol (mg/dL), (E) high-density lipoprotein (HDL) cholesterol (mg/dL), and (F) low-density lipoprotein (LDL) cholesterol (mg/dL). Studies are identified by the first author's name and year of publication.

CI, confidence interval; df, degree of freedom; GLP-1RAs, glucagon-like peptide-1 receptor agonists; IV, inverse variance; MD, mean difference; SE, standard error. (Continued to the next page)

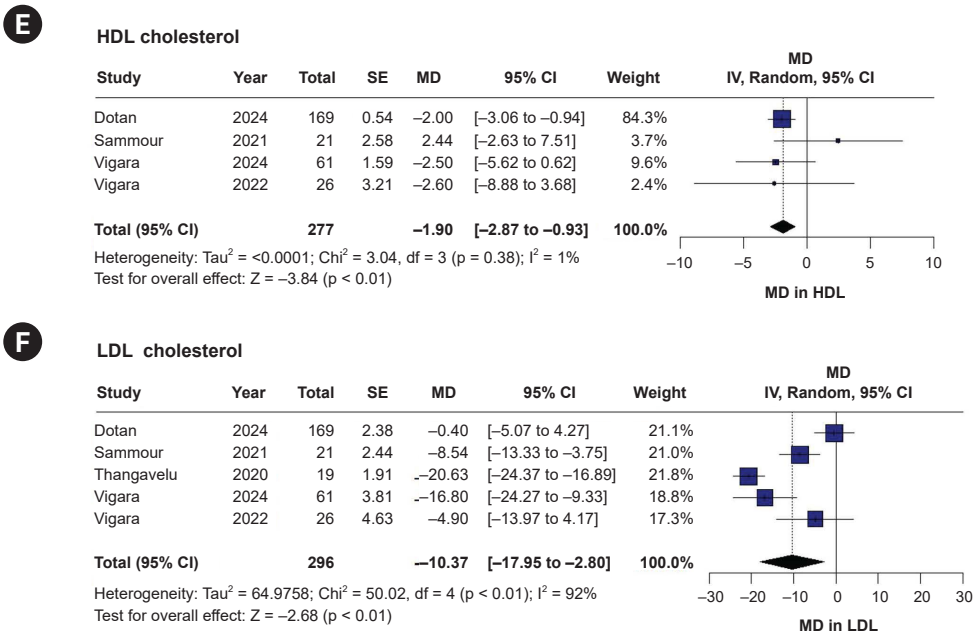


Figure 3. Continued.

(Supplementary Fig. 13) shows $I^2 = 0\%$, suggesting heterogeneity reduction.

Urine albumin-to-creatinine ratio

GLP-1RA medication has shown a significant reduction in UACR from baseline, with an MD of -2.58 mg/mmol (95% CI, -5.07 to -0.08 ; $p = 0.04$, $I^2 = 93\%$) (Fig. 4C) across four studies including 138 patients [29,32,33,40] at 12 months. Nonetheless, over a shorter length of 6 months, there was a notable reduction in UACR of -4.40 mg/mmol (95% CI, -8.25 to -0.55 ; $p = 0.03$, $I^2 = 36\%$) [29,32,33] (Supplementary Fig. 14, available online).

Fasting plasma glucose

A change in FPG was seen in seven patients before and after GLP-1RA [12,31,34,35,37–39]. The MD was -21.20 mg/dL (95% CI, -35.51 to -6.88 ; $p < 0.01$, $I^2 = 73\%$) (Fig. 4D).

Subgroup analysis showed no significant difference in FPG levels at 6-month follow-up (95% CI, -26.27 to 7.90 ; $p < 0.29$, $I^2 = 60\%$). At 12 months shows statistically significant effects, with an MD of -23.54 mg/dL (95% CI, -29.98 to -17.09 ; $p < 0.01$, $I^2 = 0\%$) (Supplementary Fig. 15, available online).

In leave-one-out analysis revealed Pinelli et al. [12] found an MD of -25.91 mg/dL (95% CI, -37.01 to -14.87 , $I^2 = 55\%$)

(Supplementary Fig. 15).

Efficacy of glucagon-like peptide-1 receptor agonists in cardiovascular diseases and mortality outcomes

In our meta-analysis of 16 studies, only two with 158 individuals investigated cardiovascular disease and death. These studies revealed one myocardial infarction, one stroke, and four heart failure cases with a prevalence of 2.53% (95% CI, 0.95 to 6.55 ; $I^2 = 0\%$) (Fig. 5A). We found three fatalities (2.1%) in three studies, with a prevalence rate of 1.41% (95% CI, 0.00 to 4.76 ; $I^2 = 0\%$) (Fig. 5B) throughout follow-up. The reason for the fatalities was not specified.

Safety outcomes

Tacrolimus levels

Eight trials including a total of 185 individuals assessed the effects of GLP-1RAs on immunosuppressive drugs [12,42–45]. The meta-analysis indicated that GLP-1RAs did not produce a significant alteration in tacrolimus trough levels relative to baseline, exhibiting an MD of -0.40 ng/mL (95% CI, -0.85 to 0.05 ; $p = 0.08$, $I^2 = 42\%$) (Fig. 5C). In subgroup analysis, alterations in tacrolimus dosage after therapy

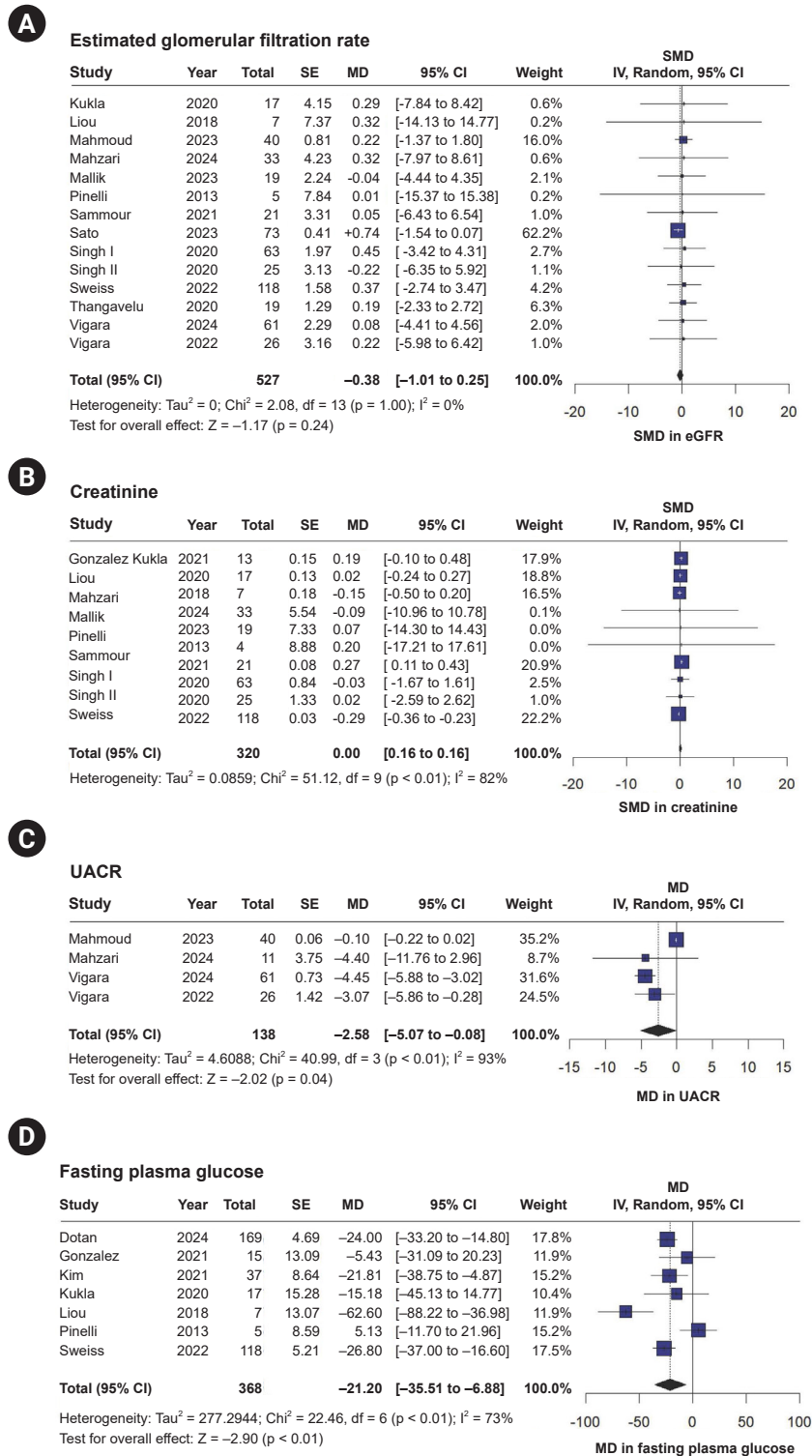


Figure 4. Forest plot of the effects of the administration of GLP-1RAs. Effects on (A) estimated glomerular filtration rate (eGFR, mL/min/1.73 m²), (B) creatinine (mmol/L), (C) urine albumin-to-creatinine ratio (UACR, mg/mmol), (D) fasting plasma glucose (mg/dL). Studies are identified by the first author's name and year of publication.

CI, confidence interval; df, degree of freedom; GLP-1RAs, glucagon-like peptide-1 receptor agonists; IV, inverse variance; MD, mean difference; SE, standard error; SMD, standardized mean difference.

with GLP-1RAs at 6 months have been reported in six trials, yielding an MD of -0.53 ng/mL (95% CI, -0.84 to -0.22 ; $p < 0.01$, $I^2 = 4\%$). Reported a substantial decrease in tacrolimus dose. At 12 months, the MD was -0.43 ng/dL (95% CI, -0.94 to 0.08 ; $p < 0.10$, $I^2 = 51\%$), indicating that GLP-1RAs did not produce a statistically significant alteration in tacrolimus trough levels relative to baseline, as shown in [Supplementary Fig. 16](#) (available online).

Adverse events

Table 2 summarizes adverse occurrences from the analyzed studies. In the four studies, five cases (1.5%) of graft rejection or graft dysfunction with prevalence of 1.25% (95% CI, 0.13–3.09; $I^2 = 0$, p heterogeneity = 0.77). For whatever reason, GLP-1RAs were discontinued 13.4%, with a prevalence of 11.28% (95% CI, 5.97–17.76). Urinary tract infection (UTI) was the most common adverse event at 21.1%, with a prevalence of 16.43% (95% CI, 5.30–40.86), nausea and vomiting at 13.9%, diarrhea at 6.3%, and injection site pain at 1.5%. Hypoglycemia was rare, occurring at 6.1% with a prevalence of 5.4% (95% CI, 1.28–11.49) in just 22 occurrences in five studies [20,28,31,32,37]. Six cases of pancreatitis (1.0%; 95% CI, 0.00–4.15; $I^2 = 29\%$ [20,28,31,35]) and three cases of pancreatic cancer (0.23%; 95% CI, 0.00–1.32; $I^2 = 0\%$ [20,28,32,33,39]) occurred during GLP-1RA treatment in five studies, as shown in [Supplementary Fig. 17](#) (available online).

Sensitivity analysis

Subgroup analyses by transplant type for T1D insulin, cholesterol, eGFR, and creatinine are shown in [Supplementary Fig. 18](#) (available online).

To enhance robustness, Singh et al. [28] were excluded due to the use of a computed pooled SD. Upon removal, significant changes remained in HbA1c (MD, -0.65% [95% CI, -0.89 to -0.42]; $p < 0.01$, $I^2 = 75\%$), weight (MD, -3.56 kg [95% CI, -4.89 to -2.24]; $p < 0.01$, $I^2 = 36\%$), BMI (MD, -1.46 kg/m² [95% CI, -2.11 to -0.81]; $p < 0.01$, $I^2 = 68\%$), and T1D (MD, -10.41 units [95% CI, -20.18 to -0.63]; $p = 0.04$, $I^2 = 73\%$) ([Supplementary Fig. 19](#), available online). eGFR and creatinine showed no significant differences ([Supplementary Fig. 20](#), available online).

An additional sensitivity analysis was conducted by ex-

cluding studies with fewer than 15 patients [12,34,38]. The results remained consistent, showing significant reductions in HbA1c, weight, BMI, eGFR, and FPG, while creatinine did not reach statistical significance ([Supplementary Fig. 21](#), available online).

Evaluation of quality assessment

Risk of bias was assessed using the RoB 1 tool [24], with no studies classified as high risk ([Supplementary Fig. 22](#), available online). Funnel plots and Egger's regression tests showed no evidence of publication bias ($p > 0.05$), except for the eGFR outcome.

In the initial analysis including Sato et al.'s study [41], there was no significant effect on eGFR and no heterogeneity. After excluding this study, the result remained nonsignificant (SMD, 0.21 mL/min/1.73 m² [95% CI, -0.82 to 1.24]; $p = 0.69$, $I^2 = 0\%$), and Egger's test showed no asymmetry ($p = 0.50$). This suggests the initial asymmetry was influenced by Sato et al. [41], but without altering the overall findings for eGFR.

Discussion

Our comprehensive review and meta-analysis of 16 studies on GLP-1RAs in SOT recipients with T2DM and/or new-onset DM after transplantation indicate a favorable antidiabetic effect in this patient population. The principal findings demonstrate improvements in HbA1c, BMI, weight, FPG, and UACR levels. GLP-1RA use in KTRs appears generally safe, with no significant changes in immunosuppressive drug levels. However, nausea, vomiting, diarrhea, UTIs, and drug discontinuation were more common.

GLP-1 receptors are activated by synthetic peptides, increasing insulin secretion and satiety. Different receptor selectivity and structural features help regulate glycaemia and weight [46]. GLP-1, an incretin produced by intestinal L cells, binds to its specific GLP-1 receptor in the bloodstream to increase glucose-stimulated insulin secretion, delay gastric transit, lower blood glucagon levels, stimulate brain anorexigenic pathways, and modulate food preferences, resulting in weight loss [42–44]. Glucose-dependent insulinotropic polypeptide (GIP), produced by intestinal K-cells, also contributes to incretin action and modulates glucagon and insulin depending on glycaemia [42,43].

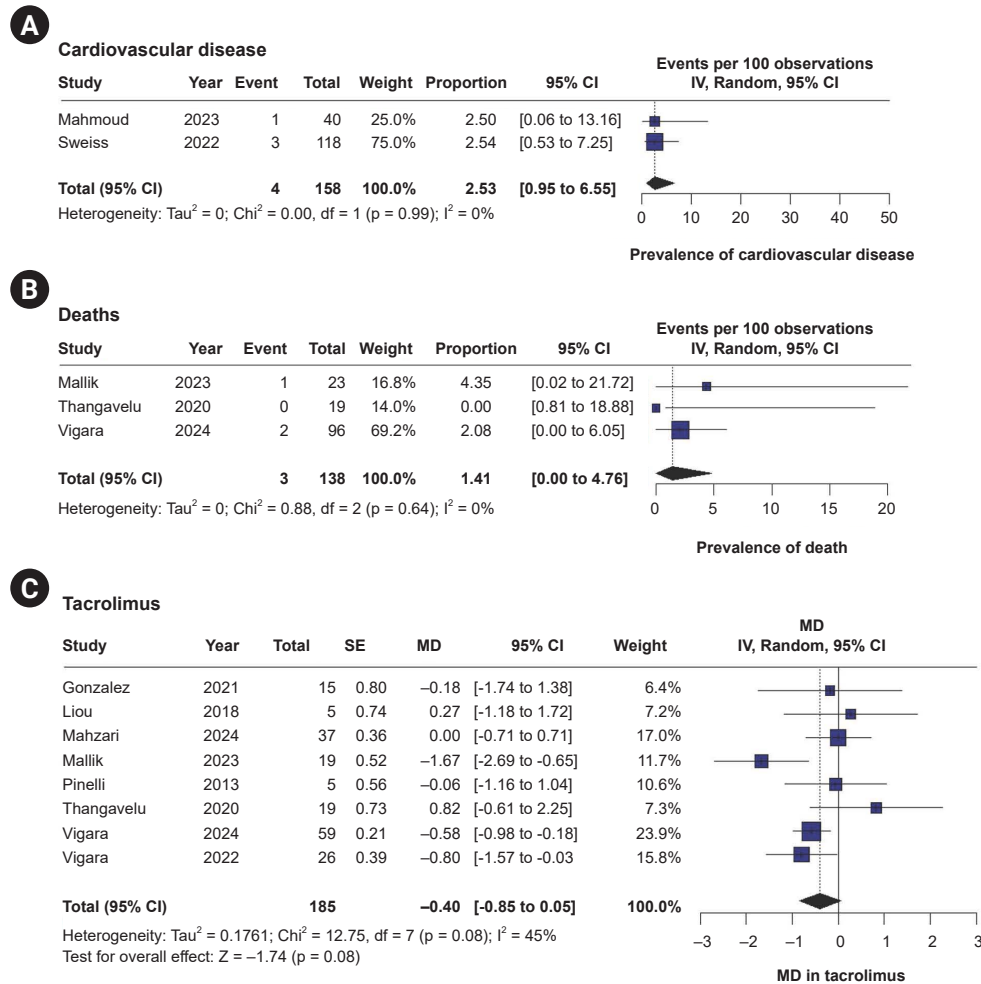


Figure 5. Forest plot of the effects of the administration of GLP-1RAs. Effects on (A) cardiovascular disease; (B) deaths (prevalence); (C) tacrolimus (ng/dL). Studies are identified by the first author's name and year of publication. CI, confidence interval; df, degree of freedom; GLP-1RAs, glucagon-like peptide-1 receptor agonists; IV, inverse variance; MD, mean difference; SE, standard error.

Though debated, combined GIP and GLP-1 receptor activation may enhance weight loss more than GLP-1RA alone [43].

The meta-analysis shows that GLP-1RAs improve glycemic management, especially HbA1c decrease in SOT patients. According to their large-scale investigation, GLP-1RAs lowered HbA1c levels and major adverse cardiovascular events risk by 12% [45]. The renal and cardiovascular benefits separate these drugs. Similar to Giugliano et al. [47], modest SBP decreases were reported. GLP-1RAs efficiently lower HbA1c and cardiovascular risk, making them ideal for high-risk patients like transplant recipients [48].

We examined more than HbA1c. A considerable decrease

in FPG supported the claim that GLP-1RA regulates blood glucose. People with T2DM had similar findings [47]. This shows the versatility of these treatments for hyperglycemia.

Dulaglutide and liraglutide, weight and BMI improved significantly. According to research, GLP-1RAs consistently caused weight reduction in varied patient populations [49]. Due to immunosuppressive medicine weight gain, transplant patients must manage their weight. Effective weight control medicines improve overall health.

Our research indicated that GLP-1RAs offered significant renal protection. Reductions in UACR and preservation of eGFR are renal health indices. Sattar et al. [48] found a 21% decrease in renal consequences such as macroalbumin-

Table 2. Adverse events

Adverse events	Patients evaluated	Event	Proportion (%)	I ² (%)	p heterogeneity
Drug discontinuation	581	78 (13.4)	11.28 (5.97–17.76)	69	<0.01
Diarrhea	299	19 (6.3)	7.83 (3.99–14.79)	55	0.05
Graft failure	318	5 (1.5)	1.25 (0.13–3.09)	0	0.77
Hypoglycemia	358	22 (6.1)	5.39 (1.28–11.49)	69	<0.01
Injection site pain	130	2 (1.5)	0.02 (0.00–2.94)	43	0.16
Nausea and vomiting	459	64 (13.9)	14.94 (10.51–20.79)	45	0.06
Pancreatic cancer	412	3 (0.7)	0.23 (0.00–1.32)	0	0.87
Pancreatitis	242	6 (2.5)	0.98 (0.00–4.15)	29	0.23
Abdominal pain	125	2 (1.6)	1.09 (0.00–5.55)	34	0.22
Urinary tract infections	76	16 (21.1)	16.43 (5.30–40.86)	66	0.05

Data are expressed as number only, number (%), or proportion (95% confidence interval).

I², heterogeneity.

uria and a slower progression to end-stage kidney disease. Kristensen et al. [45] found that GLP-1RA helps maintain kidney function, making it advantageous for those at high risk of renal complications.

A significant finding was the decrease in daily insulin usage and enhancements in lipid profiles, including reduced total cholesterol and LDL levels. Sattar et al. [48] reported analogous findings, demonstrating that GLP-1RAs not only decrease insulin requirements but also enhance cholesterol levels, thereby emphasizing their metabolic advantages.

GLP-1RAs are usually well tolerated; however, they might cause nausea, vomiting, and diarrhea. Tacrolimus, an immunosuppressant used in transplant patients, can cause diarrhea. Two medicines together may increase the risk of gastrointestinal distress, especially diarrhea. We found that tacrolimus did not worsen these effects when combined with GLP-1RAs. Sweiss et al. [31] found minor gastrointestinal problems linked with GLP-1RA but no tacrolimus interaction or adverse effect exacerbation. Sun et al. [50] found that GLP-1RA therapy causes common but temporary gastrointestinal adverse effects. Our research found no increased risk of serious adverse events, such as pancreatitis or pancreatic cancer, supporting Bethel et al.'s [51] safety profile.

Although tacrolimus-based regimens predominated in the included studies, immunosuppressant protocols vary substantially across transplant centers, limiting the generalizability of our findings to recipients on other regimens (e.g., cyclosporine, sirolimus, everolimus). Future multi-center trials should standardize or stratify immunosuppression to ensure broader applicability of these results.

Another important factor is the timing of GLP-1RA initiation posttransplantation. One study reported early initiation at 1 month posttransplant [41], while another initiated therapy between 6 months and 4 years after transplantation [29]. A study reported a median initiation time of 2.8 years and another found a mean of approximately 2 years [31,36]. Meanwhile, other studies began GLP-1RA treatment beyond the first posttransplant year [20,37,38]. Despite this variation, GLP-1RAs consistently demonstrated safety and efficacy, without adversely affecting immunosuppressant levels or graft function. These findings support the use of GLP-1RAs across various posttransplant time points as part of an individualized treatment approach.

This meta-analysis provides valuable insights into how GLP-1RAs affect glycemic control, weight management, renal protection, and cardiovascular health in SOT recipients, yet several limitations warrant attention. First, variability in transplant types and study designs contributed to heterogeneity, and only four studies included comparison groups. The absence of randomized controlled trials further limits the strength of the findings. Second, outcome variability for HbA1c, BMI, creatinine, TDD, and UACR was partly due to differences in follow-up durations, including one study with only 1 month of follow-up. Subgroup analyses were performed based on follow-up time and organ type. Third, the data gap on GLP-1RA dosing, concurrent antidiabetic medications, and under-representation of heart and pancreas transplant recipients limited generalizability. Inconsistent reporting of angiotensin-converting enzyme inhibitors, angiotensin II receptor blockers, CNIs, and corticosteroids—agents that may confound metabol-

ic and renal outcomes—compounded these challenges. Future studies should provide detailed reporting of these agents and adjust analyses accordingly. Fourth, the timing of GLP-1RA initiation was inconsistently reported, impeding assessment of its influence on outcomes. Rejection events were rarely reported, precluding a complete safety evaluation. Future research should incorporate rejection endpoints for a more complete safety profile. Finally, while Egger's test revealed no publication bias, eGFR outcomes exhibited bias that was resolved by excluding one study. Cardiovascular and mortality outcomes could not be adequately assessed due to short follow-up periods and limited data. Moreover, much of the safety data originates from heart and pancreas transplants, reducing applicability to other transplant types. Short follow-up periods and small sample sizes underscore the need for larger, longer-term investigations, ideally with control groups, to provide more robust and generalizable evidence on the long-term efficacy and safety of GLP-1RAs in SOT recipients.

Our systematic review and meta-analysis corroborate the advantageous benefits of GLP-1RA regarding efficacy and safety, notwithstanding these limitations.

Conflicts of interest

All authors have no conflicts of interest to declare.

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Data sharing statement

Additional data available in supplementary file. The data presented in this study are available from the corresponding author upon reasonable request.

Authors' contributions

Conceptualization, Methodology: MU, HY, XC, KX

Data curation: MU, HY, YZ

Funding acquisition: KX

Investigation: MU, XC, CL

Writing—original draft: MU

Writing—review & editing: All authors

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Appendix 1. Search strategies used for electronic databases

PubMed

("organ transplantation" OR "Organ Transplantation"[Mesh] OR "Transplants"[Mesh] OR transplant OR transplants OR transplantation OR transplanted OR posttransplant OR posttransplants OR "post-transplant" OR posttransplantation OR "post-transplantation diabetes mellitus") AND ("Glucagon-Like Peptide 1"[Mesh] OR "Glucagon-Like Peptide 1" OR "Glucagon-Like Peptide-1 Receptor Agonists"[Mesh] OR "glucagon-like peptide-1 receptor agonist" OR "GLP-1 agonist" OR GLP1 OR GLP1R OR "GLP1R agonist" OR "GLP-1 receptor agonists" OR GLP1 receptor agonists OR "Glucagonlike Peptide-1 receptor Agonists" OR albiglutide OR semaglutide OR exenatide OR dulaglutide OR liraglutide OR lixisenatide)

Embase

('organ transplantation' OR 'organ transplantation'/exp OR 'transplantation'/exp OR 'transplant' OR 'transplants' OR 'transplantation' OR 'transplanted' OR 'posttransplant' OR 'posttransplants' OR 'post-transplant' OR 'posttransplantation' OR 'post-transplantation diabetes mellitus') AND ('glucagon like peptide 1'/exp OR 'glucagon-like peptide 1' OR 'glucagon like peptide 1 receptor agonist'/exp OR 'glucagon-like peptide-1 receptor agonist' OR 'glp-1 agonist' OR 'glp1' OR 'glp1r' OR 'glp1r agonist' OR 'glp-1 receptor agonists' OR 'glp1 receptor agonists' OR 'glucagonlike peptide-1 receptor agonists' OR 'albiglutide' OR 'semaglutide' OR 'exenatide' OR 'dulaglutide' OR 'liraglutide' OR 'lixisenatide')

Cochrane

("organ transplantation" OR "Transplants" OR transplant OR transplants OR transplantation OR transplanted OR post-transplant OR posttransplants OR "post-transplant" OR posttransplantation OR "post-transplantation diabetes mellitus") AND ("Glucagon-Like Peptide 1" OR "glucagon-like peptide-1 receptor agonist" OR "GLP-1 agonist" OR GLP1 OR GLP1R OR "GLP1R agonist" OR "GLP-1 receptor agonists" OR GLP1 receptor agonists OR "Glucagonlike Peptide-1 receptor Agonists" OR albiglutide OR semaglutide OR exenatide OR dulaglutide OR liraglutide OR lixisenatide)

Doc type = Language = All languages.