

ORIGINAL RESEARCH

Switching to Versus Addition of Incretin-Based Drugs Among Patients With Type 2 Diabetes Taking Sodium-Glucose Cotransporter-2 Inhibitors

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BACKGROUND: Evidence is limited in comparing treatment modification by substitution or add-on of glucose-lowering medications in patients with type 2 diabetes. This observational study aims to compare switching versus add-on of incretin-based drugs among patients with type 2 diabetes on background sodium-glucose cotransporter-2 inhibitors (SGLT2i).

METHODS AND RESULTS: This population-based, retrospective cohort study was conducted using the IQVIA Medical Research Data, including adults with type 2 diabetes on background SGLT2i from 2005 to 2020. New users of incretin-based drugs were allocated into the “Switch” group if they had discontinued SGLT2i treatment, or the “Add-on” group if their background SGLT2i was continued. Baseline characteristics of patients were balanced between groups. Study outcomes were all-cause mortality, cardiovascular diseases, kidney diseases, hypoglycemia, and ketoacidosis. Patients were observed from the index date of initiating incretin-based drugs until the earliest of an outcome event, death, or data cut-off date. Changes in anthropometric and metabolic parameters were also compared between groups from baseline to 12-month follow-up. A total of 2888 patients were included, classified into “Switch” (n=1461) or “Add-on” group (n=1427). Median follow-up was 18 months with 5183 person-years. Overall, no significant differences in the risks of study outcomes were observed between groups; however, patients in the “Add-on” group achieved significantly greater reductions in glycosylated hemoglobin, weight, percentage weight loss, and systolic blood pressure than their “Switch” counterparts.

CONCLUSIONS: Initiating incretin-based drugs as add-on among patients with type 2 diabetes on background SGLT2i was associated with risks of clinical end points comparable to switching treatments, in addition to better glycemic and weight control observed with the combination approach.

Key Words: add-on therapy ■ dipeptidyl peptidase-4 inhibitor ■ glucagon-like peptide-1 receptor agonist ■ sodium-glucose cotransporter-2 inhibitor ■ switching therapy ■ type 2 diabetes

Considering the progressive nature of type 2 diabetes (T2D), patients often require multiple anti-diabetic agents over their course of disease for optimal glycemic control, where the stepwise approach of initiating new glucose-lowering medications

following the failure of existing therapy in meeting individualized glycosylated hemoglobin (HbA1c) targets remains the preferred regimen by various international guidelines.¹⁻⁴ When treatment intensification is needed sequential to first-line metformin monotherapy,

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CLINICAL PERSPECTIVE

What Is New?

- In this retrospective cohort study of patients with type 2 diabetes who were on background sodium-glucose cotransporter-2 inhibitors (SGLT2i), new users of incretin-based drugs were allocated into the “Switch” group if they had discontinued SGLT2i treatment, or the “Add-on” group if their background sodium-glucose cotransporter-2 inhibitors was continued.
- Over a median follow-up of 18 months, no significant differences in the risks of all-cause mortality, cardiovascular diseases, kidney diseases, hypoglycemia, and ketoacidosis were observed between groups.
- Patients in the “Add-on” group achieved significantly greater reductions in glycated hemoglobin, weight, percentage weight loss, and systolic blood pressure than their “Switch” counterparts.

What Are the Clinical Implications?

- While no significant differences in the risks of various clinical end points were identified between switching and add-on approaches in the current study, they should be interpreted with caution given the relatively short follow-up period and hence the small number of events that occurred.
- Meanwhile, several metabolic benefits of the combination (“Add-on”) approach were significantly greater than that of switching, including better glycemic control, reduction in weight and blood pressure over 12-month follow-up.
- Further studies with longer observation periods and randomized controlled trials are needed to clarify the risks and benefits of the 2 treatment modalities.

Nonstandard Abbreviations and Acronyms

| | |
|---------------|---|
| CCI | Charlson Comorbidity Index |
| DPP4i | dipeptidyl peptidase-4 inhibitors |
| ESKD | end-stage kidney disease |
| GLP1RA | glucagon-like peptide-1 receptor agonists |
| IMRD | IQVIA Medical Research Data |
| IPTW | inverse probability of treatment weights |
| SBP | systolic blood pressure |
| SGLT2i | sodium-glucose cotransporter-2 inhibitors |
| T2D | type 2 diabetes |

introduction of antidiabetic drugs with complementary mechanisms of action is recommended to help address the ominous octet of T2D pathophysiology.^{5–8} Among the different drug classes, sodium-glucose cotransporter-2 inhibitors (SGLT2i) offer substantial metabolic benefits beyond glycemic control, reducing the risks of cardiovascular diseases (CVD), progression of diabetic nephropathy, and mortality, in addition to promoting weight loss, lowering blood pressure (BP), and incurring a low risk of hypoglycemia.^{1,8–11} With increasing availability and its repositioning as a second-line glucose-lowering medication,^{1,2,4,10,11} it can be anticipated that an increasing number of patients will be put on a combination regimen of metformin and SGLT2i, and it would be intriguing to explore the preferred option for subsequent treatment intensification.

Incretin-based therapy consisting of dipeptidyl peptidase-4 inhibitors (DPP4i) and glucagon-like peptide-1 receptor agonists (GLP1RA) are alternative antidiabetic agents with demonstrated efficacy and general tolerability.^{1,8} While specific GLP1RA have exerted beneficial effects in terms of cardiovascular outcomes, especially lowering the risks of major adverse cardiovascular events and mortality, alongside considerable weight loss and BP reduction,^{2,9–12} DPP4i are less potent in the stimulation of incretin effect. Hence they are mostly associated with cardiovascular neutrality and clinical benefits of a smaller magnitude than GLP1RA.^{1,8,13,14} Because both drug classes act by promoting insulin secretion while suppressing that of glucagon in a glucose-dependent manner, they may compensate for the increased glucagon level and endogenous glucose production induced by SGLT2i to facilitate better glycemic control, and offer distinct mechanisms of action in targeting the metabolic defects of T2D that are complementary to those of metformin and SGLT2i, respectively, all without posing an additional risk of hypoglycemia.^{14–18} Accordingly, incretin-based drugs appear to be an attractive option over sulfonylureas or thiazolidinediones as treatment intensification, with respect to cardiorenal outcomes, clinical parameters, and risk of hypoglycemia.^{1,14}

Aside from the selection of antidiabetic agents based on patient preferences, cardiorenal status, and drug safety profile, the choice of drug initiation approach may also influence therapeutic efficacy via factors such as medication burden and patient adherence, correction of T2D pathophysiology, time to achieving individualized targets, clinical inertia, and overall cost-effectiveness that takes diabetic complications into account.^{1,6,8} A retrospective cohort study utilizing electronic medical records from the UK Clinical Practice Research Datalink (CPRD) found that among patients with T2D with inadequate glycemic control, adding a new glucose-lowering medication

was associated with clinically significant reduction in HbA1c, which was not evident among those switching to another therapy or continuing with the original treatment.¹⁹ Recently, several clinical trials and meta-analyses have demonstrated that the combination of SGLT2i with incretin-based drugs may produce sub-additive or additive effects in glycemic control and improvements in metabolic parameters than either drug class with placebo^{20–26}; yet, there is very limited evidence on the comparison of cardiorenal end points and mortality for combination therapy versus each treatment alone.^{27,28}

With reference to clinical guidelines recommending the substitution and/or addition of new anti-diabetic agents upon limited response to existing glucose-lowering therapy, as well as the research gap in evaluating any additional cardiorenal benefits of combining SGLT2i with incretin-based drugs over individual treatments and across different patient subgroups,^{9,10,12,14,18,29,30} this observational study aims to compare the all-cause mortality, cardiorenal outcomes, adverse effects, and changes in clinical parameters associated with incretin-based drugs as switching versus add-on therapy among patients with T2D on background SGLT2i in a real-life setting. Because glucose-lowering medications with duplicating mechanisms of action are generally not recommended in combination regimens,⁶ this study will consider the initiation of DPP4i or GLP1RA as substitution versus add-on to SGLT2i separately, and compare their safety and efficacy under respective treatment condition.

METHODS

Data Source and Study Design

This population-based, retrospective cohort study was conducted using the IMRD, a database comprising anonymized electronic primary health care records for 15 million patients from >750 general practices across the United Kingdom. IMRD incorporates data supplied by The Health Improvement Network, a proprietary database of Cegedim SA. It contains coded patient-level longitudinal information on demographics, symptoms, clinical diagnoses recorded using Read Codes, medication prescriptions, consultations, and anthropometric, clinical, and laboratory measures. The data set is representative of the UK population by age, sex, medical conditions, and death rates adjusted for demographics, and has similar distribution of major chronic diseases, including diabetes, CVD, and mental illnesses, compared with the UK national statistics.^{31,32} Validity of the diagnoses of ischemic cerebrovascular events and chronic kidney disease (CKD) with Read Codes in The Health Improvement Network database has been confirmed,^{33,34} in addition to the accuracy

of diabetes, hypertension, and CVD.³⁵ Studies have utilized this database to explore the associations between glucose-lowering medications and mortality, macrovascular, and microvascular diseases in patients with T2D.^{36–38} We implemented a new user design based on IMRD data. New users of incretin-based drugs were first-time-ever users of GLP1RA or DPP4i drugs.

Study Population

General practices were included in the study from the latest of the following dates: 12 months after reporting acceptable mortality rates (a measure of data-recording quality), 12 months after beginning the use of electronic medical records, and study start date (January 1, 2005). This was to maximize data and recording quality.³⁹

People aged ≥ 18 years who had registered with an eligible general practice for a minimum of 12 months, with a record of T2D (using Read codes in Table S1 or Chapter 6.1 of the British National Formulary), and received 2 or more consecutive prescriptions for SGLT2i drug, were eligible for inclusion. Prescriptions of SGLT2i, GLP1RA, and DPP4i were identified using drug codes (Table S1). Eligible patients were categorized into the “Switch” group if they had initiated prescriptions for index incretin-based drugs, either GLP1RA or DPP4i drug, but discontinued that of SGLT2i, defined by either the absence of ongoing refills or a gap of 60 days; or “Add-on” group if they had received prescriptions for incretin-based drugs while not discontinuing that of background SGLT2i. Patients in the “Add-on” group with overlapping duration of 2 drug classes of <60 days were excluded. The date of initiating incretin-based drugs was considered the index date (baseline).

Follow-Up Period

Participants were followed up from the index date until the earliest of the following occurrences: outcome diagnosis, death, participant left the practice, practice ceased to contribute to the database, or the end of study (June 30, 2020).

Baseline Covariates

Baseline covariates of patients included age, sex, smoking status, drinking status, duration of T2D, duration of SGLT2i prescription, anthropometric and clinical measurements, laboratory readings, drug prescription within 1 year, and comorbidity status at baseline. Baseline body mass index, fasting glucose, HbA1c, average systolic blood pressure (SBP) and diastolic blood pressure within 1 year before baseline, total cholesterol to high-density lipoprotein-cholesterol ratio, low-density lipoprotein-cholesterol, and triglycerides were

taken from the closest reading before the index date. The estimated glomerular filtration rate (eGFR) was estimated by serum creatinine, age, and sex based on the Modification of Diet in Renal Disease Study formula. Use of insulin, oral antidiabetic drugs (metformin, sulfonylureas, and thiazolidinediones), antihypertensive drugs (in particularly angiotensin-converting enzyme inhibitors/angiotensin receptor blockers), lipid-lowering agents, antiplatelets, and anticoagulants at baseline were identified using the prescription records within 1-year window before the index date. Past medical records of bariatric surgery were also extracted. Presence of any CVD, heart failure (HF), atrial fibrillation, hypertension, CKD, end-stage kidney disease (ESKD), diabetic retinopathy, peripheral neuropathy, mental or psychiatric disorder, and cancer were documented at baseline, as well as the comorbidity status determined by Charlson Comorbidity Index. The occurrence of hypoglycemia and ketoacidosis within 1 year before the index date was also recorded.

Outcome Measures

Study outcomes were all-cause mortality, CVD (composite of coronary heart disease, acute myocardial infarction, other ischemic heart disease, HF, stroke, transient ischemic attack, and peripheral vascular disease), HF (an outcome of interest with SGLT2i use), CKD, ESKD, hypoglycemia, and ketoacidosis by treatment groups. Outcome events and comorbidities were identified by Read Codes (Table S1). The diagnosis of CKD was identified by relevant Read Codes,³³ 2 consecutive measurements of eGFR <60 mL/min per 1.73 m², or 2 consecutive measurements of urine albumin-creatinine ratio ≥30 mg/g⁴⁰; and ESKD by recorded eGFR of <15 mL/min per 1.73 m². Secondary outcomes were changes in anthropometric (SBP, diastolic blood pressure, body mass index, percentage total weight loss) and metabolic (HbA1c, low-density lipoprotein-cholesterol, total cholesterol/high-density lipoprotein-cholesterol, triglycerides, eGFR) parameters from baseline to 12-month follow-up (the assessment closest to 12-month follow-up over the period of 6–18 months).

Statistical Analysis

To account for incomplete baseline data, multiple imputation by chained equations was performed. Each missing baseline datum was imputed 5 times by random chained equation using other known baseline covariates. Five complete imputed data sets were analyzed individually to generate model estimates, which were then pooled into to a single estimate using Rubin's rules.

For confounding adjustment, inverse probability of treatment weights (IPTW) using the propensity score

was applied to balance covariates across 2 treatment groups. Logistic regression models were fitted by using the indicator variables of treatment group as the dependent variable and baseline covariates as independent variables. The predicted probability of receiving treatment based on the patient's baseline covariates in the model is called propensity score. Patients with similar propensity scores were classified as having similar characteristics. We applied IPTW based on the propensity scores. Propensity score weights <1st percentile or >99th percentile in each group were trimmed. In the context of IPTW, multiple imputation followed by pooling treatment effect estimates across imputed data sets is the preferred approach.⁴¹ Balance of baseline covariates between groups were assessed using the standardized mean difference, with a value of <0.1 indicating balance.

Number of outcome events, person-years, and incidence rate with 95% Poisson CI for each treatment group were calculated. Cox proportional hazards regression model was used to examine the association between treatment groups and incidence of events, and estimate hazard ratios (HR) of treatment effects and their 95% CI. Proportional hazard assumption was tested by Schoenfeld residuals with *P* values adjusted by Bonferroni method.

Secondary outcomes were compared between baseline and 12-month follow-up by paired *t* test within the same treatment group. Effects of switching from SGLT2i (dapagliflozin or empagliflozin) to either GLP1RA (exenatide or liraglutide) or DPP4i (sitagliptin, linagliptin, or alogliptin) were assessed, whereas the effects of initiating GLP1RA or DPP4i in addition to SGLT2i were investigated within the Add-on group.

Subgroup analyses were conducted based on incretin-based drug class (GLP1RA or DPP4i); stratification of baseline HbA1c (≤9% versus >9%); any prescription records of insulin, metformin, or sulfonylureas within 1 year before baseline; and types of SGLT2i (dapagliflozin or empagliflozin), GLP1RA (exenatide or liraglutide), and DPP4i (sitagliptin, linagliptin, or alogliptin) used (which were administered by >20% of patients). In sensitivity analyses, different scenarios were tested to assess the robustness of treatment effects, including (1) "as-treated" analysis to censor the follow-up period at the discontinuation of incretin-based drugs, subsequent switch from GLP1RA to DPP4i, or switch from DPP4i to GLP1RA; (2) competing risk analysis accounting for competing risk of death; (3) multiple imputation of missing baseline covariates without IPTW; and (4) complete-case with IPTW.

All statistical analyses were performed using Stata version 16.0 (StataCorp LP, College Station, Texas). All significance tests were 2-tailed and *P* values of <0.05 were taken to indicate statistical significance.

Ethical Approval

Use of the IMRD database has been approved by the NHS Health Research Authority (NHS Research Ethics Committee reference: 18/LO/0441); in accordance with this approval, the study protocol was reviewed and approved by an independent Scientific Review Committee (reference number: 20SRC070). This study used de-identified data provided by patients as part of their routine primary care, and no informed consent was required for this study.

RESULTS

Among 31 171 adults with T2D receiving 2 or more consecutive prescription records of SGLT2i, a total of 2888 patients had initiated incretin-based drugs and received 2 or more consecutive prescription records of GLP1RA or DPP4i on or after January 1, 2005, of whom 1461 were switched from SGLT2i to incretin-based drugs (Switch group: GLP1RA $n=412$; DPP4i $n=1049$), while 1427 were prescribed with a combination of SGLT2i and incretin-based drugs (Add-on group: GLP1RA $n=409$; DPP4i $n=1018$) (Figure 1). Background SGLT2i therapy had been initiated for a mean of 1.4 (SD 1.1) years at baseline (Table 1). The 3 types of SGLT2i used were dapagliflozin (60.2%), empagliflozin (27.7%), and canagliflozin (12.1%). Over half (52.6%) of the patients used exenatide for GLP1RA initiation, followed by liraglutide (32.3%), dulaglutide (10.7%), and lixisenatide (4.4%). For patients initiating DPP4i, 39.2% used sitagliptin, 25.0% used linagliptin, 24.6% used alogliptin, 10.8% used saxagliptin, and 0.3% used vildagliptin. Baseline characteristics of patients in the 2 treatment groups after multiple imputation and weighting are listed in Table 1. Overall, the mean age of this cohort was 57.9 (SD 11.2) years, with baseline HbA1c of 9.0% (1.5%), duration of T2D for 8.7 (6.4) years, and Charlson Comorbidity Index of 4.1 (1.9). Demographic and clinical characteristics of patients were balanced between groups. Data completion rates of baseline covariates are detailed in Table S2.

The median follow-up period of patients in Switch and Add-on groups were 19.2 (interquartile range, 9.1–34.6) and 17.0 (8.0–28.5) months, respectively (Table 2). After weighting, incidence rate of all-cause mortality during follow-up was 11.82 and 12.57 per 1000 person-years among Switch and Add-on users, respectively. Overall, there were no significant difference in risks of all-cause mortality (HR, 0.908 [95% CI, 0.541–1.523]; $P=0.713$), CVD (HR, 0.746 [95% CI, 0.464–1.198]; $P=0.225$), HF (HR, 1.238 [95% CI, 0.501–3.058]; $P=0.644$), CKD (HR, 1.128 [95% CI, 0.761–1.670]; $P=0.549$), ESKD (HR, 1.942 [95% CI, 0.205–18.433]; $P=0.563$), hypoglycemia (HR, 1.180 [95% CI, 0.595–2.342]; $P=0.636$), and ketoacidosis (HR, 0.854 [95% CI, 0.113–6.480]; $P=0.879$)

between treatment groups (Table 3). Similar risks of outcome events were observed between the 2 groups across subgroup and sensitivity analyses (Tables S3 and S4, respectively). Test for proportional hazard assumption by Schoenfeld residuals showed there is no evidence that the proportional hazard assumption has been violated.

Changes in anthropometric and laboratory parameters from baseline to 12-month follow-up were also compared within each treatment group (Figure 2) and by differences between the 2 groups (Figure S1). A significantly greater reduction in mean HbA1c (-0.7% versus -0.5% , $P<0.001$) was observed in the Add-on group compared with the Switch group, which were also evident among DPP4i users. When stratified by glycemic control at baseline, considerably larger decreases in HbA1c were noted at 12-month follow-up among patients with baseline level of $>9\%$ than those with $\leq 9\%$. In addition, patients in the Add-on group managed to achieve greater mean reduction in weight (-2.4 versus -0.7 kg, $P<0.001$) and percentage total weight loss (2.2% versus 0.5%, $P<0.001$) than those in the Switch group, regardless of the incretin-based drug class. A significantly larger decrease in body mass index (-0.8 versus -0.2 kg/m², $P<0.001$) was evident among Add-on versus Switch users, particularly with DPP4i. While within-group changes in SBP were statistically insignificant, a trend towards BP lowering among patients in the Add-on group resulted in a significant difference from those in the Switch group (-1.1 versus 0.5 mm Hg, $P=0.047$). Notably, a larger decrease in total cholesterol/high-density lipoprotein-cholesterol ratio was only significant among DPP4i users of Add-on versus Switch treatment groups. Overall, there were no significant differences in 12-month changes of DBP, low-density lipoprotein-cholesterol, triglycerides, and eGFR between the Switch and Add-on groups.

DISCUSSION

In this cohort of patients with T2D with inadequate glycemic control despite being on a background glucose-lowering therapy of SGLT2i and other antidiabetic agents, no significant differences in the risks of all-cause mortality, cardiorenal outcomes, and other clinical end points were identified between the initiation of incretin-based drugs as substitution or addition to the existing drug regimen. Nevertheless, treatment modification with the stepwise combination approach (add-on) resulted in significant improvements of several metabolic parameters over 12-month follow-up compared with replacing SGLT2i with another new drug class (switch).

To our knowledge, the study design of this “new user” retrospective cohort analysis is unique in terms

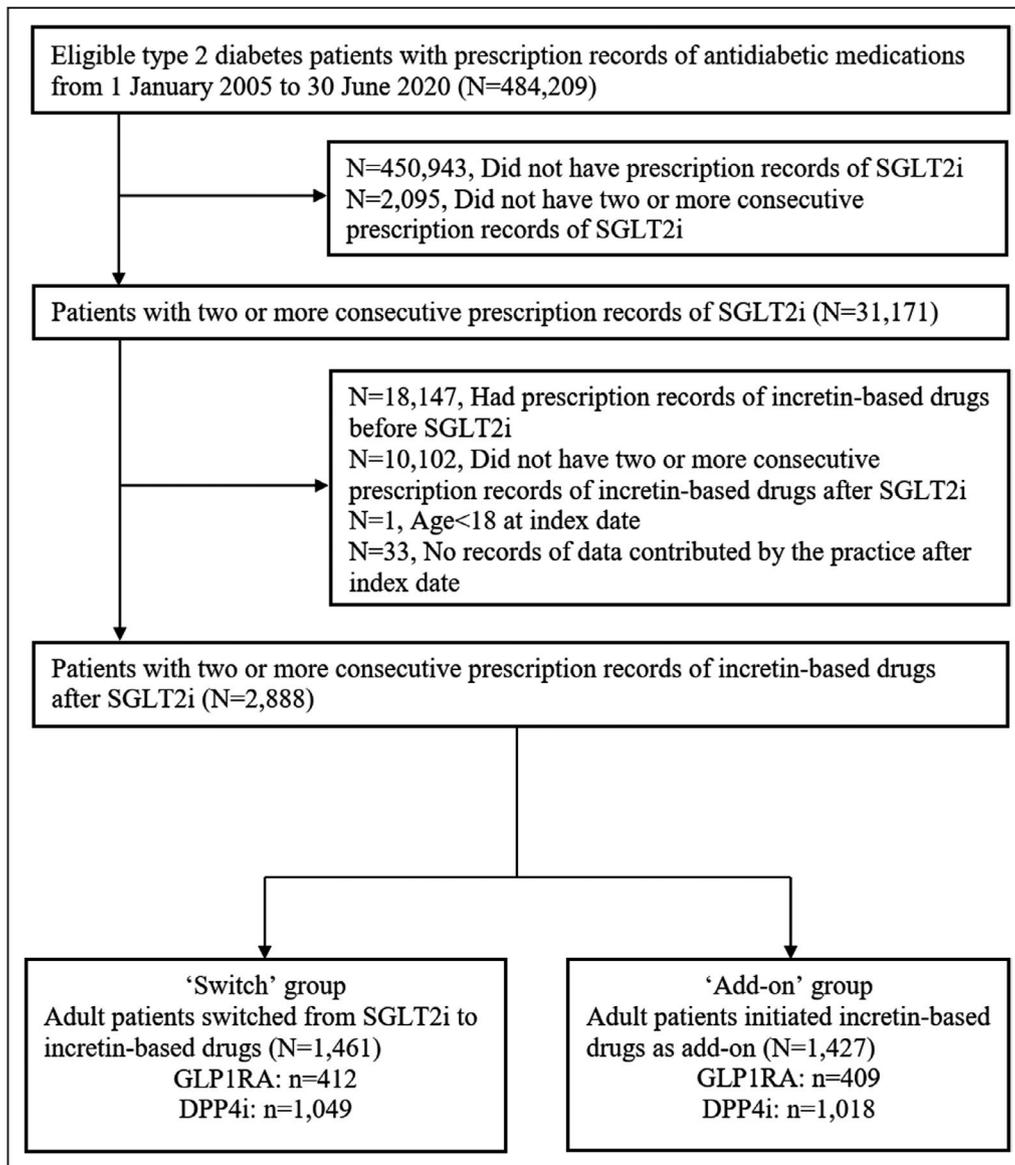


Figure 1. Flowchart of identifying eligible patients with type 2 diabetes who had initiated incretin-based drugs as substitution (“Switch”) or add-on (“Add-on”) to background SGLT2i therapy.

DPP4i indicates dipeptidyl peptidase-4 inhibitors; GLP1RA, glucagon-like peptide-1 receptor agonists; and SGLT2i, sodium-glucose cotransporter-2 inhibitors.

of comparing multiple clinical end points and metabolic changes with respect to the adjustment of treatment modalities and the selection of newer antidiabetic agents (namely, SGLT2i and incretin-based drugs). The current literature is limited and inconclusive on any additional benefits of combining SGLT2i with incretin-based drugs in reducing the macrovascular and microvascular complications of diabetes. While a post hoc analysis of DECLARE-TIMI 58 concluded that the addition of dapagliflozin to baseline use of GLP1RA could lower the risks of hospitalization for heart failure and a composite of cardiovascular mortality and hospitalization for heart failure versus placebo, another post hoc analysis of EXSCEL could only observe significant risk reduction in

all-cause and cardiovascular death with the combination of exenatide plus SGLT2i versus either placebo or exenatide alone, alongside a trend towards reducing the risk of major adverse cardiovascular events.^{27,42} Regarding specific renal outcomes (composite of eGFR reduction, ESKD, or renal death; and new-onset albuminuria), the former study also demonstrated a trend towards benefit for the addition of dapagliflozin versus placebo to baseline DPP4i or GLP1RA therapy.⁴² Similarly, using sulfonylureas as an active comparator, an observational cohort study of propensity score-matched patients with T2D found that adding SGLT2i to background GLP1RA therapy could lower the risks of composite cardiovascular outcomes and hospitalization for heart failure.²⁸

Table 1. Baseline Characteristics of Patients With Type 2 Diabetes Who Initiated Incretin-Based Drugs as Substitution (“Switch”) or Add-on to SGLT2i Before and After Propensity Score Weighting

| Baseline characteristics | Before weighting | | | | After weighting |
|--------------------------------------|------------------|-----------------|-----------------|------|-----------------|
| | Total (N=2888) | Switch (N=1461) | Add-on (N=1427) | SMD | SMD |
| Socio-demographics | | | | | |
| Sex (%) | | | | 0.15 | 0.01 |
| Female | 46.3% | 50.0% | 42.5% | | |
| Male | 53.7% | 50.0% | 57.5% | | |
| Age (mean±SD), y | 57.9 (11.2) | 58.8 (11.6) | 57.0 (10.8) | 0.16 | 0.03 |
| Clinical characteristics (mean±SD) | | | | | |
| SBP, mm Hg | 131.6 (13.9) | 132.1 (13.8) | 131.1 (14.1) | 0.07 | 0.00 |
| DBP, mm Hg | 77.9 (9.0) | 77.8 (8.8) | 78.0 (9.3) | 0.02 | 0.00 |
| BMI, kg/m ² | 34.7 (7.0) | 34.8 (7.0) | 34.5 (7.0) | 0.03 | 0.01 |
| <25 | 4.9% | 5.3% | 4.5% | 0.07 | 0.08 |
| 25 to <30 | 22.4% | 21.2% | 23.7% | | |
| 30 to <35 | 28.8% | 28.5% | 29.0% | | |
| ≥35 | 43.9% | 45.0% | 42.8% | | |
| Weight, kg | 99.1 (21.9) | 98.7 (22.0) | 99.5 (21.7) | 0.03 | 0.01 |
| TC, mmol/L | 4.5 (1.2) | 4.5 (1.1) | 4.5 (1.2) | 0.01 | 0.02 |
| LDL-C, mmol/L | 2.7 (1.2) | 2.7 (1.2) | 2.8 (1.1) | 0.04 | 0.02 |
| TC/HDL-C ratio | 4.2 (1.5) | 4.2 (1.5) | 4.2 (1.5) | 0.01 | 0.00 |
| Triglyceride, mmol/L | 2.7 (2.0) | 2.6 (1.9) | 2.7 (2.1) | 0.04 | 0.03 |
| Fasting glucose, mmol/L | 11.1 (4.8) | 11.1 (4.9) | 11.1 (4.8) | 0.00 | 0.01 |
| HbA1c, % | 9.0 (1.5) | 9.0 (1.6) | 9.0 (1.4) | 0.02 | 0.00 |
| ≤7 | 3.3% | 3.8% | 2.7% | 0.07 | 0.05 |
| >7 to 9 | 54.4% | 53.5% | 55.4% | | |
| >9 | 42.3% | 42.7% | 41.9% | | |
| Creatinine (serum), μmol/L | 74.7 (20.4) | 75.5 (23.8) | 73.8 (16.3) | 0.08 | 0.06 |
| eGFR, mL/min per 1.73 m ² | 114.1 (29.6) | 112.3 (30.4) | 116.0 (28.7) | 0.12 | 0.01 |
| Urine ACR, mg/g | 58.2 (257.5) | 64.4 (303.9) | 51.5 (195.7) | 0.05 | 0.00 |
| Lifestyle factors (%) | | | | | |
| Smoking status | | | | 0.03 | 0.06 |
| Nonsmoker | 47.8% | 47.6% | 47.9% | | |
| Current smoker | 16.6% | 16.2% | 17.1% | | |
| Ex-smoker | 35.6% | 36.1% | 35.0% | | |
| Drinking status | | | | 0.04 | 0.02 |
| Nondrinker | 26.2% | 26.9% | 25.5% | | |
| Current drinker | 67.6% | 66.7% | 68.4% | | |
| Ex-drinker | 6.2% | 6.3% | 6.1% | | |
| Comorbidity status (%) | | | | | |
| Cardiovascular diseases | 19.0% | 20.5% | 17.4% | 0.08 | 0.02 |
| Heart failure | 2.5% | 2.9% | 2.1% | 0.05 | 0.02 |
| Atrial fibrillation | 4.7% | 5.9% | 3.6% | 0.11 | 0.01 |
| Hypertension | 59.0% | 60.3% | 57.7% | 0.05 | 0.01 |
| Chronic kidney disease | 19.6% | 21.8% | 17.4% | 0.11 | 0.02 |
| End-stage kidney disease | 0.1% | 0.1% | 0.1% | 0.02 | 0.01 |
| Diabetic retinopathy | 20.7% | 19.7% | 21.7% | 0.05 | 0.00 |
| Peripheral neuropathy | 10.2% | 11.6% | 8.8% | 0.09 | 0.01 |
| Mental or psychiatric disorder | 19.2% | 19.6% | 18.9% | 0.02 | 0.02 |

(Continued)

Table 1. (Continued)

| Baseline characteristics | Before weighting | | | After weighting | |
|----------------------------------|------------------|-----------------|-----------------|-----------------|------|
| | Total (N=2888) | Switch (N=1461) | Add-on (N=1427) | SMD | SMD |
| Cancer | 5.5% | 6.0% | 4.9% | 0.05 | 0.00 |
| Hypoglycemia within 1 y | 1.0% | 1.2% | 0.8% | 0.05 | 0.00 |
| Ketoacidosis within 1 y | 0.1% | 0.1% | 0.1% | 0.02 | 0.01 |
| Charlson comorbidity index* | 4.1 (1.9) | 4.3 (2.0) | 3.9 (1.8) | 0.20 | 0.03 |
| Charlson comorbidity index*, (%) | | | | 0.18 | 0.10 |
| 1–2 | 19.3% | 18.5% | 20.0% | | |
| 3 | 24.4% | 20.9% | 27.9% | | |
| 4 or above | 56.4% | 60.5% | 52.1% | | |
| Duration of type 2 diabetes, y | 8.7 (6.4) | 8.8 (6.6) | 8.6 (6.1) | 0.03 | 0.00 |
| Treatment use within 1 y (%) | | | | | |
| Insulin | 57.3% | 61.3% | 53.1% | 0.17 | 0.02 |
| Basal insulin | 11.3% | 13.3% | 9.1% | 0.13 | 0.10 |
| Oral antidiabetic drugs | | | | | |
| Metformin | 91.9% | 92.1% | 91.6% | 0.02 | 0.00 |
| SU | 45.9% | 50.8% | 40.9% | 0.20 | 0.01 |
| TZD | 8.3% | 9.7% | 6.9% | 0.10 | 0.01 |
| Antihypertensive drugs | | | | | |
| ACEI/ARB | 64.7% | 65.0% | 64.4% | 0.01 | 0.00 |
| Lipid-lowering drugs | 84.0% | 82.8% | 85.4% | 0.07 | 0.01 |
| Antiplatelet drugs | 28.9% | 29.6% | 28.2% | 0.03 | 0.00 |
| Anticoagulant | 7.9% | 9.8% | 5.9% | 0.15 | 0.03 |
| Bariatric surgery | 0.5% | 0.4% | 0.5% | 0.01 | 0.02 |
| Duration of SGLT2i, y | 1.4 (1.1) | 1.3 (1.1) | 1.5 (1.2) | 0.14 | 0.02 |
| Drug type (%) | | | | | |
| SGLT2i | | | | 0.12 | 0.03 |
| Canagliflozin | 12.1% | 14.0% | 10.2% | | |
| Dapagliflozin (Propanediol) | 60.2% | 58.8% | 61.6% | | |
| Empagliflozin | 27.7% | 27.2% | 28.2% | | |
| GLP1RA | | | | 0.28 | 0.04 |
| Exenatide | 52.6% | 48.8% | 56.5% | | |
| Dulaglutide | 10.7% | 14.8% | 6.6% | | |
| Liraglutide | 32.3% | 32.5% | 32.0% | | |
| Lixisenatide | 4.4% | 3.9% | 4.9% | | |
| DPP4i | | | | 0.10 | 0.03 |
| Sitagliptin | 39.2% | 39.5% | 39.0% | | |
| Vildagliptin | 0.3% | 0.6% | 0.1% | | |
| Saxagliptin | 10.8% | 11.0% | 10.5% | | |
| Linagliptin | 25.0% | 25.4% | 24.7% | | |
| Alogliptin | 24.6% | 23.6% | 25.7% | | |

ACEI indicates angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blockers; BMI, body mass index; DBP, diastolic blood pressure; DPP4i, dipeptidyl peptidase-4 inhibitor; eGFR, estimated glomerular filtration rate; GLP-1RA, glucagon-like peptide-1 receptor agonists; HbA1c, hemoglobin A1c; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; SBP, systolic blood pressure; SGLT2i, sodium glucose cotransporter-2 inhibitors; SMD, standardized mean difference; SU, sulfonylureas; TZD, thiazolidinedione; and Urine ACR, urine albumin-to-creatinine ratio.

*The calculation of Charlson Comorbidity Index does not include acquired immune deficiency syndrome (AIDS).

Contrary to the few existing studies that explored the cardiorenal outcomes and mortality of SGLT2i and incretin-based drug combination relative to placebo,

either treatment alone, or an active comparator, this study focused on evaluating these effects on new users of GLP1RA or DPP4i who had received SGLT2i

Table 2. Number and Incidence Rate of All-Cause Mortality, Cardiovascular Diseases, Heart Failure, Chronic Kidney Disease, End-Stage Kidney Disease, Hypoglycemia, and Ketoacidosis Events

| Events | Before weighting | | | | After weighting | | | |
|--------------------------|----------------------|-------|--|----------------|-----------------------------------|---------------------------------|--------------------------------------|----------------|
| | Cumulative incidence | | Crude incidence rate (Cases / 1000 person-y) | | Median follow-up periods (Months) | | Incidence rate (Cases/1000 person-y) | |
| | Cases with event | Rate | Estimate | 95% CI* | Person-y | Mean follow-up periods (Months) | Estimate | 95% CI* |
| Total (N=2888) | | | | | | | | |
| All-cause mortality | 64 | 2.22% | 12.35 | (9.51, 15.77) | 5183 | 18 | 12.20 | (10.15, 14.48) |
| Cardiovascular diseases | 75 | 3.21% | 18.43 | (14.49, 23.10) | 4070 | 17 | 19.53 | (16.58, 22.74) |
| Heart failure | 21 | 0.75% | 4.17 | (2.58, 6.37) | 5041 | 18 | 4.11 | (2.92, 5.51) |
| Chronic kidney disease | 112 | 4.83% | 28.13 | (23.16, 33.85) | 3981 | 17 | 27.39 | (23.89, 31.23) |
| End-stage kidney disease | 4 | 0.14% | 0.77 | (0.21, 1.98) | 5170 | 18 | 0.76 | (0.30, 1.44) |
| Hypoglycemia | 38 | 1.33% | 7.47 | (5.28, 10.25) | 5089 | 18 | 7.81 | (6.17, 9.68) |
| Ketoacidosis | 4 | 0.14% | 0.77 | (0.21, 1.98) | 5173 | 18 | 0.75 | (0.30, 1.44) |
| Switch (N=1461) | | | | | | | | |
| All-cause mortality | 36 | 2.46% | 12.90 | (9.04, 17.87) | 2790 | 19 | 11.82 | (9.02, 15.08) |
| Cardiovascular diseases | 37 | 3.19% | 17.06 | (12.02, 23.52) | 2168 | 19 | 17.04 | (13.28, 21.45) |
| Heart failure | 13 | 0.92% | 4.82 | (2.57, 8.24) | 2699 | 19 | 4.55 | (2.85, 6.74) |
| Chronic kidney disease | 64 | 5.60% | 31.04 | (23.90, 39.63) | 2062 | 17 | 28.95 | (23.93, 34.70) |
| End-stage kidney disease | 3 | 0.21% | 1.08 | (0.22, 3.15) | 2779 | 19 | 0.98 | (0.31, 2.22) |
| Hypoglycemia | 23 | 1.59% | 8.43 | (5.35, 12.65) | 2727 | 19 | 8.41 | (6.03, 11.22) |
| Ketoacidosis | 2 | 0.14% | 0.72 | (0.09, 2.59) | 2786 | 19 | 0.73 | (0.16, 1.81) |
| Add-on (N=1427) | | | | | | | | |
| All-cause mortality | 28 | 1.96% | 11.70 | (7.77, 16.91) | 2393 | 17 | 12.57 | (9.64, 15.92) |
| Cardiovascular diseases | 38 | 3.23% | 19.98 | (14.14, 27.42) | 1902 | 16 | 22.10 | (17.70, 27.09) |
| Heart failure | 8 | 0.57% | 3.42 | (1.47, 6.73) | 2342 | 17 | 3.67 | (2.17, 5.71) |
| Chronic kidney disease | 48 | 4.07% | 25.01 | (18.44, 33.16) | 1919 | 16 | 25.85 | (21.14, 31.26) |
| End-stage kidney disease | 1 | 0.07% | 0.42 | (0.01, 2.33) | 2391 | 17 | 0.53 | (0.08, 1.54) |
| Hypoglycemia | 15 | 1.06% | 6.35 | (3.55, 10.47) | 2362 | 17 | 7.20 | (5.01, 9.85) |
| Ketoacidosis | 2 | 0.14% | 0.84 | (0.10, 3.03) | 2387 | 17 | 0.77 | (0.16, 1.83) |

DPP4i indicates dipeptidyl peptidase-4 inhibitor; GLP-1RA, glucagon-like peptide-1 receptor agonists; and SGLT2i, sodium glucose cotransporter-2 inhibitors.
 *95% CI of incidence rates were constructed by Poisson distribution.

Table 3. HR of All-cause Mortality, Cardiovascular Diseases, Heart Failure, Chronic Kidney Disease, End-Stage Kidney Disease, Hypoglycemia, and Ketoacidosis Events

| Events | Switch vs Add-on | | |
|--------------------------|------------------|----------------|---------|
| | HR | 95% CI | P value |
| All-cause mortality | 0.908 | (0.541–1.523) | 0.713 |
| Cardiovascular disease | 0.746 | (0.464–1.198) | 0.225 |
| Heart failure | 1.238 | (0.501–3.058) | 0.644 |
| Chronic kidney disease | 1.128 | (0.761–1.670) | 0.549 |
| End-stage kidney disease | 1.942 | (0.205–18.433) | 0.563 |
| Hypoglycemia | 1.180 | (0.595–2.342) | 0.636 |
| Ketoacidosis | 0.854 | (0.113–6.480) | 0.879 |

HR indicates hazard ratio.

therapy for a mean of 1.4 years, and attempted to answer the intriguing question of whether switching to another new drug class or adding it to the existing drug regimen would influence patient outcomes in real-world clinical practice. This research question is of clinical relevance because patient adherence could be affected by factors including pill burden, treatment complexity, and medication cost; whereas a combination of antidiabetic agents with distinct mechanisms of action could potentially offer additional benefits to glycemic and metabolic control by targeting different pathophysiological defects of T2D,^{6,7,14} which remains to be proven and justified. While no significant differences in the risks of developing various clinical end points between switching and add-on could be identified in the current study, they should be interpreted with caution given the relatively short follow-up period and hence the small number of events that occurred.

In theory, the combination of SGLT2i with incretin-based drugs could exert complementary actions on cardiorenal protection and ameliorating adverse effects, with SGLT2i mainly lowering the risks of HF and diabetic nephropathy via hemodynamic benefits, GLP1RA acting to reduce major adverse cardiovascular events with anti-atherogenic and anti-inflammatory properties, and DPP4i attenuating the elevated risk of genital infections associated with SGLT2i use through modulating the immune system.^{7,14,18,43,44} Furthermore, SGLT2i may compensate for the possible negative actions of GLP1RA and potential risk of specific DPP4i in HF progression, while incretin-based drugs may alleviate the development of ketoacidosis associated with SGLT2i use by counteracting its increased glucagon secretion and subsequent ketogenesis.^{14,29,45,46} Nevertheless, it has also been proposed that the production of ketone bodies induced by SGLT2i may partly be responsible for its decrease in cardiac and renal workload, and hence the observed clinical benefits;

therefore, any complementary effects of SGLT2i and incretin-based drug combination may depend on the degree of glucagon suppression, duration of pharmacological treatment, and any changes in drug efficacy over time.⁴⁵

Regarding the choice of treatment modality, our results were consistent with that of the retrospective cohort study utilizing the UK CPRD, demonstrating that the add-on approach could achieve HbA1c reduction substantially larger than that of switching therapy, when patients were showing limited response to the original drug regimen¹⁹; however, changes in other anthropometric and metabolic parameters have not been compared between the 2 treatment approaches. This study suggested that, in addition to better glycemic control, the stepwise combination (add-on) therapy could produce reduction in weight and SBP significantly larger than that of substituting SGLT2i with incretin-based drugs over 12-month follow-up, which were generally in line with several clinical trials observing greater improvements with the addition of GLP1RA or DPP4i to SGLT2i versus placebo add-on or either drug class alone.^{23,25,47–50} While these studies would be classified as the comparison between “adding a new drug class” and “continuing the original therapy,” our study provided further evidence to support the use of “combination therapy” (add-on) over “replacing SGLT2i with incretin-based drugs” (switching) in terms of metabolic changes.

With reference to the pharmacological profile of these 3 drug classes, it can be postulated that GLP1RA would exert compensatory effects on the increased glucagon level and endogenous glucose production of SGLT2i to further reduce the HbA1c level, promote additive weight loss via the suppression of appetite to counteract the reported increase in food intake associated with SGLT2i use, and produce a synergistic effect on BP lowering with vasodilation and mild natriuresis that are distinct from SGLT2i-induced natriuresis and reduction of intravascular volume.^{7,14,29,43} Notably, reduction in HbA1c has also been consistently shown to be sub-additive with the combination of SGLT2i and incretin-based drugs versus either treatment alone, which could be attributed to the interference of drugs combined and the failure of GLP1RA or DPP4i in adequately blocking the elevated endogenous glucose production of SGLT2i, especially at higher HbA1c levels.^{7,14,17,18,20,51} Yet, our results reinforced the proposition that add-on or combination therapy would facilitate better glycemic control, even when compared with switching from a drug class with “limited response” to another with different mechanisms of action.

Concerning the initiation of DPP4i to existing SGLT2i therapy, our study revealed that the add-on approach could result in significantly larger reduction in HbA1c,

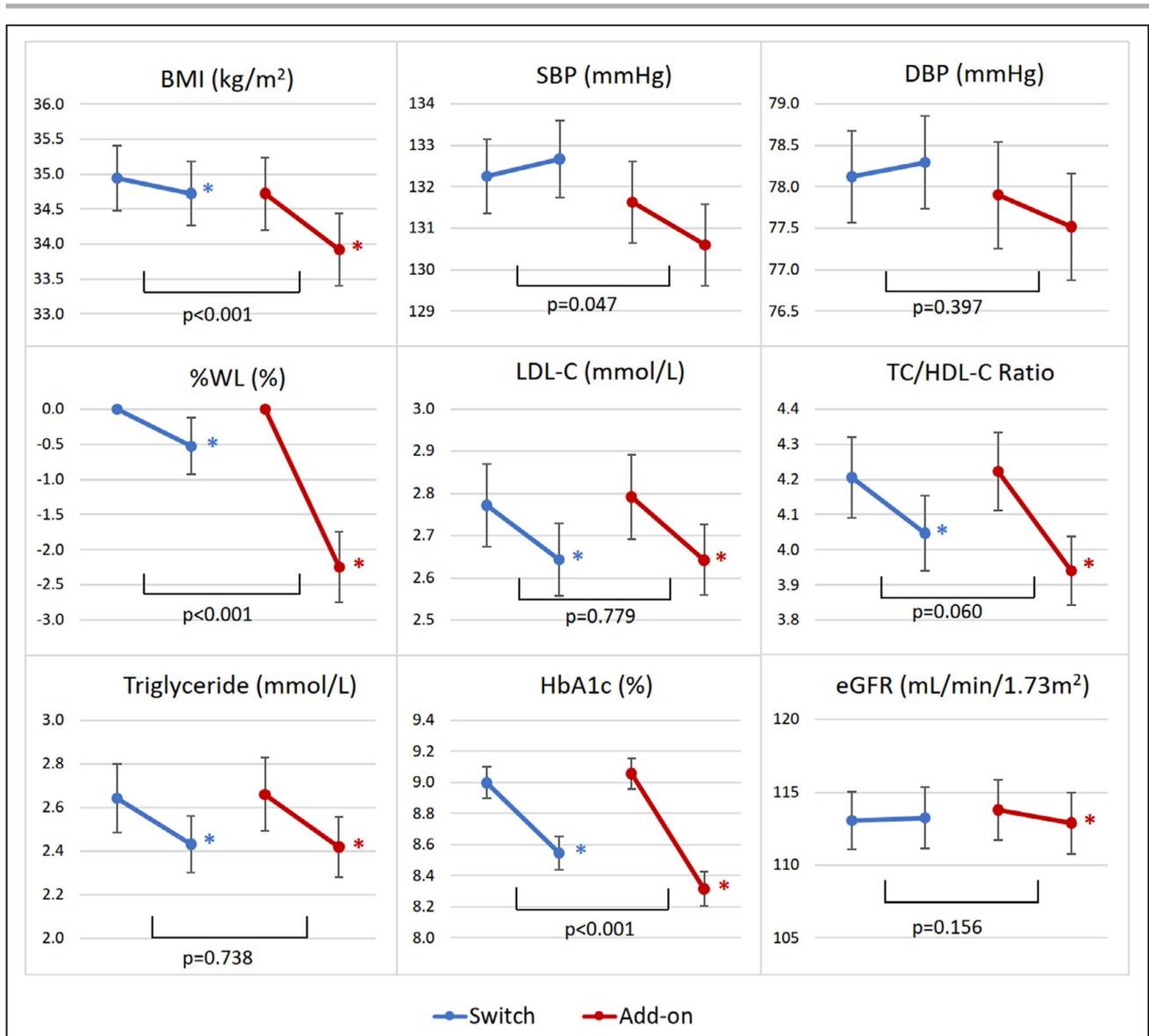


Figure 2. Mean and 95% CI of 12-month changes in anthropometric and laboratory parameters of patients with type 2 diabetes who had initiated incretin-based drugs as substitution (“Switch”) or add-on (“Add-on”) to background SGLT2i therapy.

%WL indicates percentage weight loss; BMI, body mass index; DBP, diastolic blood pressure; eGFR, estimated glomerular filtration rate; HbA1c, glycated hemoglobin; HDL-C, high-density lipoprotein-cholesterol; LDL-C, low-density lipoprotein-cholesterol; SBP, systolic blood pressure; SGLT2i, sodium-glucose cotransporter 2 inhibitors; and TC, total cholesterol. *Significant difference ($P < 0.05$) in mean of change from baseline to 12-month follow-up.

weight, and total cholesterol/high-density lipoprotein-cholesterol ratio than that of substitution or switching. While some studies argued that beyond glycemic control, the addition of DPP4i to SGLT2i might not confer any additional benefits on weight loss, lowering BP, or improving the lipid profile compared with SGLT2i alone,^{14,18,20,22} our study suggested that the combination therapy would be preferred to discontinuing SGLT2i and replacing it with DPP4i. Consistent with the fact that DPP4i is weight neutral and generally less potent than GLP1RA (including the suppression of

endogenous glucose production), initiation of the latter could produce more clinically relevant reduction in HbA1c, weight, and BP.^{10,13,14,18,49} Nonetheless, DPP4i may still offer renal benefits in terms of decreasing albuminuria,⁴² and can be an alternative to patients preferring an oral route of administration.

Utilizing the IMRD representative of the United Kingdom population, this study attempted to evaluate the clinical and metabolic outcomes of patients with T2D initiating incretin-based drugs as substitution for (switching) or in combination with (add-on) background

SGLT2i therapy in the real-world setting. Various baseline characteristics of patients had been taken into account, which were further adjusted with multiple imputations and propensity score weighting to balance the confounding factors between groups. Despite such unique study design in addressing the clinical question of whether switching or add-on would be the preferred treatment approach, and the focus on newer antidiabetic agents with demonstrated cardiorenal safety or benefits, several limitations of this study should be acknowledged. First, given that SGLT2i is a relatively new drug class approved for T2D management, the follow-up period of new users of incretin-based drugs who had been on previous SGLT2i therapy would be fairly short, and hence the small number of events occurred over a median of 18 months. This could limit the interpretation of our results, because differences in cardiovascular or renal events might not be evident within this short observation period. Accordingly, our study might be underpowered to draw definite conclusions about cardiorenal outcomes, in addition to our limited sample size. Second, this patient cohort had relatively poor glycemic (mean HbA1c 9.0%) and metabolic control at baseline; thus the current findings might not be generalizable to other patient populations with different clinical characteristics. Furthermore, this patient cohort had a mean duration of diabetes of 8.7 years and were prescribed various glucose-lowering medications within 1 year at baseline; hence the results would not be applicable to patients with T2D at an earlier stage of the disease. Third, over half of the GLP1RA users in this cohort were prescribed exenatide, which is not associated with cardio- or renoprotective effects, while none were given semaglutide, which is associated with reduction in major adverse cardiovascular events, stroke, composite renal outcome, and mortality.⁹ Such drug type distribution might have influenced our results. Fourth, biological mechanisms of the greater metabolic benefits observed with the add-on approach versus switching therapy remain to be elucidated. Some unmeasured confounding factors might have also played a role in the significant differences, such as more intensive therapy and lifestyle management of the metabolic risk factors in patients managed by physicians pursuing the add-on approach. Lastly, cost-effectiveness of different treatment modalities and quality of life indices of patients were not evaluated in the current study, which would also be relevant in the decision-making process.

CONCLUSIONS

In this patient cohort with T2D with inadequate glycaemic control on background SGLT2i therapy, no significant differences in the risks of developing various

clinical end points could be identified in the initiation of incretin-based drugs as substitution (switching) or add-on to the existing drug regimen. Meanwhile, several metabolic benefits of the combination approach were significantly greater than that of switching, including the reduction of HbA1c, weight, and SBP over 12-month follow-up. Further studies with longer observation periods and randomized controlled trials are needed to clarify the risks and benefits of the 2 treatment modalities.

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Data Availability Statement

The IQVIA Medical Research Data (IMRD) were obtained from IQVIA. For further information on access to the database, please contact IQVIA (contact details can be found at <https://www.iqvia.com/locations/united-kingdom/information-for-members-of-the-public/medical-research-data>).

Supplemental Material

Data S1

Tables S1–S4

Figure S1

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SUPPLEMENTAL MATERIAL

Data S1. STROBE Statement—Checklist of items that should be included in reports of *cohort studies*

| | Item No | Recommendation | Page No |
|------------------------------|----------------|---|----------------|
| Title and abstract | 1 | (a) Indicate the study's design with a commonly used term in the title or the abstract | 2-3 |
| | | (b) Provide in the abstract an informative and balanced summary of what was done and what was found | 2-3 |
| Introduction | | | |
| Background/rationale | 2 | Explain the scientific background and rationale for the investigation being reported | 5-7 |
| Objectives | 3 | State specific objectives, including any prespecified hypotheses | 7 |
| Methods | | | |
| Study design | 4 | Present key elements of study design early in the paper | 7-9 |
| Setting | 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | 7-9 |
| Participants | 6 | (a) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up | 7-9 |
| | | (b) For matched studies, give matching criteria and number of exposed and unexposed | 9-10 |
| Variables | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | 9-11 |
| Data sources/ measurement | 8* | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group | 10-11 |
| Bias | 9 | Describe any efforts to address potential sources of bias | 11 |
| Study size | 10 | Explain how the study size was arrived at | Fig 1 |
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | 12 |
| Statistical methods | 12 | (a) Describe all statistical methods, including those used to control for confounding | 11-13 |
| | | (b) Describe any methods used to examine subgroups and interactions | 12 |
| | | (c) Explain how missing data were addressed | 11 |
| | | (d) If applicable, explain how loss to follow-up was addressed | 9 |
| | | (e) Describe any sensitivity analyses | 12 |
| Results | | | |
| Participants | 13* | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed | Fig 1 |
| | | (b) Give reasons for non-participation at each stage | Fig 1 |
| | | (c) Consider use of a flow diagram | Fig 1 |
| Descriptive data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | 13-14 |

| | | | |
|--------------------------|-----|--|---------------------|
| | | (b) Indicate number of participants with missing data for each variable of interest | Supp Table2 |
| | | (c) Summarise follow-up time (eg, average and total amount) | 14, Table2 |
| Outcome data | 15* | Report numbers of outcome events or summary measures over time | 14-15 |
| Main results | 16 | (a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | 14-15 |
| | | (b) Report category boundaries when continuous variables were categorized | NA |
| | | (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period | NA |
| Other analyses | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses | 14, Supp Tables 3-4 |
| Discussion | | | |
| Key results | 18 | Summarise key results with reference to study objectives | 15 |
| Limitations | 19 | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias | 20 |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | 16-20 |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | 16-20 |
| Other information | | | |
| Funding | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based | 22 |

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting.

The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>).

Information on the STROBE Initiative is available at <http://www.strobe-statement.org>.

Table S1. Read codes of comorbidities and event outcomes.

Cardiovascular diseases

| | |
|---------|---|
| G3...00 | Ischaemic heart disease |
| G3...11 | Arteriosclerotic heart disease |
| G3...12 | Atherosclerotic heart disease |
| G3...13 | IHD - Ischaemic heart disease |
| G30..00 | Acute myocardial infarction |
| G30..11 | Attack - heart |
| G30..12 | Coronary thrombosis |
| G30..13 | Cardiac rupture following myocardial infarction (MI) |
| G30..14 | Heart attack |
| G30..15 | MI - acute myocardial infarction |
| G30..16 | Thrombosis - coronary |
| G30..17 | Silent myocardial infarction |
| G300.00 | Acute anterolateral infarction |
| G301.00 | Other specified anterior myocardial infarction |
| G301000 | Acute anteroapical infarction |
| G301100 | Acute anteroseptal infarction |
| G301z00 | Anterior myocardial infarction NOS |
| G302.00 | Acute inferolateral infarction |
| G303.00 | Acute inferoposterior infarction |
| G304.00 | Posterior myocardial infarction NOS |
| G305.00 | Lateral myocardial infarction NOS |
| G306.00 | True posterior myocardial infarction |
| G307.00 | Acute subendocardial infarction |
| G307000 | Acute non-Q wave infarction |
| G307100 | Acute non-ST segment elevation myocardial infarction |
| G308.00 | Inferior myocardial infarction NOS |
| G309.00 | Acute Q-wave infarct |
| G30A.00 | Mural thrombosis |
| G30B.00 | Acute posterolateral myocardial infarction |
| G30X.00 | Acute transmural myocardial infarction of unspecif site |
| G30X000 | Acute ST segment elevation myocardial infarction |
| G30y.00 | Other acute myocardial infarction |
| G30y000 | Acute atrial infarction |
| G30y100 | Acute papillary muscle infarction |
| G30y200 | Acute septal infarction |
| G30yz00 | Other acute myocardial infarction NOS |
| G30z.00 | Acute myocardial infarction NOS |
| G31..00 | Other acute and subacute ischaemic heart disease |
| G310.00 | Postmyocardial infarction syndrome |

G310.11 Dressler's syndrome
 G311.00 Preinfarction syndrome
 G311.11 Crescendo angina
 G311.12 Impending infarction
 G311.13 Unstable angina
 G311.14 Angina at rest
 G311000 Myocardial infarction aborted
 G311011 MI - myocardial infarction aborted
 G311100 Unstable angina
 G311200 Angina at rest
 G311300 Refractory angina
 G311400 Worsening angina
 G311500 Acute coronary syndrome
 G311z00 Preinfarction syndrome NOS
 G312.00 Coronary thrombosis not resulting in myocardial infarction
 G31y.00 Other acute and subacute ischaemic heart disease
 G31y000 Acute coronary insufficiency
 G31y100 Microinfarction of heart
 G31y200 Subendocardial ischaemia
 G31y300 Transient myocardial ischaemia
 G31yz00 Other acute and subacute ischaemic heart disease NOS
 G32..00 Old myocardial infarction
 G32..11 Healed myocardial infarction
 G32..12 Personal history of myocardial infarction
 G33..00 Angina pectoris
 G330.00 Angina decubitus
 G330000 Nocturnal angina
 G330z00 Angina decubitus NOS
 G331.00 Prinzmetal's angina
 G331.11 Variant angina pectoris
 G332.00 Coronary artery spasm
 G33z.00 Angina pectoris NOS
 G33z000 Status anginosus
 G33z100 Stenocardia
 G33z200 Syncope anginosa
 G33z300 Angina on effort
 G33z400 Ischaemic chest pain
 G33z500 Post infarct angina
 G33z600 New onset angina
 G33z700 Stable angina
 G33zz00 Angina pectoris NOS
 G34..00 Other chronic ischaemic heart disease
 G340.00 Coronary atherosclerosis

G340.11 Triple vessel disease of the heart
 G340.12 Coronary artery disease
 G340000 Single coronary vessel disease
 G340100 Double coronary vessel disease
 G341.00 Aneurysm of heart
 G341.11 Cardiac aneurysm
 G341000 Ventricular cardiac aneurysm
 G341100 Other cardiac wall aneurysm
 G341111 Mural cardiac aneurysm
 G341200 Aneurysm of coronary vessels
 G341300 Acquired atrioventricular fistula of heart
 G341z00 Aneurysm of heart NOS
 G342.00 Atherosclerotic cardiovascular disease
 G343.00 Ischaemic cardiomyopathy
 G344.00 Silent myocardial ischaemia
 G34y.00 Other specified chronic ischaemic heart disease
 G34y000 Chronic coronary insufficiency
 G34y100 Chronic myocardial ischaemia
 G34yz00 Other specified chronic ischaemic heart disease NOS
 G34z.00 Other chronic ischaemic heart disease NOS
 G34z000 Asymptomatic coronary heart disease
 G35..00 Subsequent myocardial infarction
 G350.00 Subsequent myocardial infarction of anterior wall
 G351.00 Subsequent myocardial infarction of inferior wall
 G353.00 Subsequent myocardial infarction of other sites
 G35X.00 Subsequent myocardial infarction of unspecified site
 G36..00 Certain current complication follow acute myocardial infarct
 G360.00 Haemopericardium/current comp folow acut myocard infarct
 G361.00 Atrial septal defect/curr comp folow acut myocardal infarct
 G362.00 Ventric septal defect/curr comp fol acut myocardal infarctn
 G363.00 Ruptur cardiac wall w/out haemopericard/cur comp fol ac MI
 G364.00 Ruptur chordae tendinae/curr comp fol acute myocard infarct
 G365.00 Rupture papillary muscle/curr comp fol acute myocard infarct
 G366.00 Thrombosis atrium,auric append&vent/curr comp foll acute MI
 G37..00 Cardiac syndrome X
 G38..00 Postoperative myocardial infarction
 G380.00 Postoperative transmural myocardial infarction anterior wall
 G381.00 Postoperative transmural myocardial infarction inferior wall
 G382.00 Postoperative transmural myocardial infarction other sites
 G383.00 Postoperative transmural myocardial infarction unspec site
 G384.00 Postoperative subendocardial myocardial infarction
 G38z.00 Postoperative myocardial infarction, unspecified
 G39..00 Coronary microvascular disease

| | |
|---------|--|
| G3y..00 | Other specified ischaemic heart disease |
| G3z..00 | Ischaemic heart disease NOS |
| Gyu3.00 | [X]Ischaemic heart diseases |
| Gyu3000 | [X]Other forms of angina pectoris |
| Gyu3100 | [X]Other current complicatns following acute myocard infarct |
| Gyu3200 | [X]Other forms of acute ischaemic heart disease |
| Gyu3300 | [X]Other forms of chronic ischaemic heart disease |
| Gyu3400 | [X]Acute transmural myocardial infarction of unspecif site |
| Gyu3500 | [X]Subsequent myocardial infarction of other sites |
| Gyu3600 | [X]Subsequent myocardial infarction of unspecified site |
| 1O1..00 | Heart failure confirmed |
| 2JZ..00 | On optimal heart failure therapy |
| 662f.00 | New York Heart Association classification - class I |
| 662g.00 | New York Heart Association classification - class II |
| 662h.00 | New York Heart Association classification - class III |
| 662i.00 | New York Heart Association classification - class IV |
| 8B29.00 | Cardiac failure therapy |
| G58..00 | Heart failure |
| G58..11 | Cardiac failure |
| G580.00 | Congestive heart failure |
| G580.11 | Congestive cardiac failure |
| G580.12 | Right heart failure |
| G580.13 | Right ventricular failure |
| G580.14 | Biventricular failure |
| G580000 | Acute congestive heart failure |
| G580100 | Chronic congestive heart failure |
| G580200 | Decompensated cardiac failure |
| G580300 | Compensated cardiac failure |
| G580400 | Congestive heart failure due to valvular disease |
| G581.00 | Left ventricular failure |
| G581.11 | Asthma - cardiac |
| G581.13 | Impaired left ventricular function |
| G581000 | Acute left ventricular failure |
| G582.00 | Acute heart failure |
| G583.00 | Heart failure with normal ejection fraction |
| G583.11 | HFNEF - heart failure with normal ejection fraction |
| G583.12 | Heart failure with preserved ejection fraction |
| G584.00 | Right ventricular failure |
| G58z.00 | Heart failure NOS |
| G58z.12 | Weak heart |
| G5y4z00 | Post cardiac operation heart failure NOS |
| 661M500 | Heart failure self-management plan agreed |
| 661N500 | Heart failure self-management plan review |

662p.00 Heart failure 6 month review
 662T.00 Congestive heart failure monitoring
 662W.00 Heart failure annual review
 679W100 Education about deteriorating heart failure
 8H2S.00 Admit heart failure emergency
 8HBE.00 Heart failure follow-up
 8HTL000 Referral to rapid access heart failure clinic
 G232.00 Hypertensive heart&renal dis wth (congestive) heart failure
 G234.00 Hyperten heart&renal dis+both(congestv)heart and renal fail
 G581.12 Pulmonary oedema - acute
 G58z.11 Weak heart
 SP11111 Heart failure as a complication of care
 SP11200 Cardiorespiratory failure as a complication of care
 G554000 Congestive cardiomyopathy
 G6...00 Cerebrovascular disease
 G60..00 Subarachnoid haemorrhage
 G600.00 Ruptured berry aneurysm
 G601.00 Subarachnoid haemorrhage from carotid siphon and bifurcation
 G602.00 Subarachnoid haemorrhage from middle cerebral artery
 G603.00 Subarachnoid haemorrhage from anterior communicating artery
 G604.00 Subarachnoid haemorrhage from posterior communicating artery
 G605.00 Subarachnoid haemorrhage from basilar artery
 G606.00 Subarachnoid haemorrhage from vertebral artery
 G60X.00 Subarachnoid haemorrh from intracranial artery, unspecif
 G60z.00 Subarachnoid haemorrhage NOS
 G61..00 Intracerebral haemorrhage
 G61..11 CVA - cerebrovascular accid due to intracerebral haemorrhage
 G61..12 Stroke due to intracerebral haemorrhage
 G610.00 Cortical haemorrhage
 G611.00 Internal capsule haemorrhage
 G612.00 Basal nucleus haemorrhage
 G613.00 Cerebellar haemorrhage
 G614.00 Pontine haemorrhage
 G615.00 Bulbar haemorrhage
 G616.00 External capsule haemorrhage
 G617.00 Intracerebral haemorrhage, intraventricular
 G618.00 Intracerebral haemorrhage, multiple localized
 G619.00 Lobar cerebral haemorrhage
 G61X.00 Intracerebral haemorrhage in hemisphere, unspecified
 G61X000 Left sided intracerebral haemorrhage, unspecified
 G61X100 Right sided intracerebral haemorrhage, unspecified
 G61z.00 Intracerebral haemorrhage NOS
 G62..00 Other and unspecified intracranial haemorrhage

| | |
|---------|---|
| G620.00 | Extradural haemorrhage - nontraumatic |
| G621.00 | Subdural haemorrhage - nontraumatic |
| G622.00 | Subdural haematoma - nontraumatic |
| G623.00 | Subdural haemorrhage NOS |
| G62z.00 | Intracranial haemorrhage NOS |
| G63..00 | Precerebral arterial occlusion |
| G63..11 | Infarction - precerebral |
| G63..12 | Stenosis of precerebral arteries |
| G630.00 | Basilar artery occlusion |
| G631.00 | Carotid artery occlusion |
| G631.11 | Stenosis, carotid artery |
| G631.12 | Thrombosis, carotid artery |
| G632.00 | Vertebral artery occlusion |
| G633.00 | Multiple and bilateral precerebral arterial occlusion |
| G634.00 | Carotid artery stenosis |
| G63y.00 | Other precerebral artery occlusion |
| G63y000 | Cerebral infarct due to thrombosis of precerebral arteries |
| G63y100 | Cerebral infarction due to embolism of precerebral arteries |
| G63z.00 | Precerebral artery occlusion NOS |
| G64..00 | Cerebral arterial occlusion |
| G64..11 | CVA - cerebral artery occlusion |
| G64..12 | Infarction - cerebral |
| G64..13 | Stroke due to cerebral arterial occlusion |
| G640.00 | Cerebral thrombosis |
| G640000 | Cerebral infarction due to thrombosis of cerebral arteries |
| G641.00 | Cerebral embolism |
| G641.11 | Cerebral embolus |
| G641000 | Cerebral infarction due to embolism of cerebral arteries |
| G64z.00 | Cerebral infarction NOS |
| G64z.11 | Brainstem infarction NOS |
| G64z.12 | Cerebellar infarction |
| G64z000 | Brainstem infarction |
| G64z100 | Wallenberg syndrome |
| G64z111 | Lateral medullary syndrome |
| G64z200 | Left sided cerebral infarction |
| G64z300 | Right sided cerebral infarction |
| G64z400 | Infarction of basal ganglia |
| G65..00 | Transient cerebral ischaemia |
| G65..11 | Drop attack |
| G65..12 | Transient ischaemic attack |
| G65..13 | Vertebro-basilar insufficiency |
| G650.00 | Basilar artery syndrome |
| G650.11 | Insufficiency - basilar artery |

G651.00 Vertebral artery syndrome
 G651000 Vertebro-basilar artery syndrome
 G652.00 Subclavian steal syndrome
 G653.00 Carotid artery syndrome hemispheric
 G654.00 Multiple and bilateral precerebral artery syndromes
 G655.00 Transient global amnesia
 G656.00 Vertebrobasilar insufficiency
 G657.00 Carotid territory transient ischaemic attack
 G65y.00 Other transient cerebral ischaemia
 G65z.00 Transient cerebral ischaemia NOS
 G65z000 Impending cerebral ischaemia
 G65z100 Intermittent cerebral ischaemia
 G65zz00 Transient cerebral ischaemia NOS
 G66..00 Stroke and cerebrovascular accident unspecified
 G66..11 CVA unspecified
 G66..12 Stroke unspecified
 G66..13 CVA - Cerebrovascular accident unspecified
 G660.00 Middle cerebral artery syndrome
 G661.00 Anterior cerebral artery syndrome
 G662.00 Posterior cerebral artery syndrome
 G663.00 Brain stem stroke syndrome
 G664.00 Cerebellar stroke syndrome
 G665.00 Pure motor lacunar syndrome
 G666.00 Pure sensory lacunar syndrome
 G667.00 Left sided CVA
 G668.00 Right sided CVA
 G669.00 Cerebral palsy, not congenital or infantile, acute
 G67..00 Other cerebrovascular disease
 G670.00 Cerebral atherosclerosis
 G670.11 Precerebral atherosclerosis
 G671.00 Generalised ischaemic cerebrovascular disease NOS
 G671000 Acute cerebrovascular insufficiency NOS
 G671100 Chronic cerebral ischaemia
 G671z00 Generalised ischaemic cerebrovascular disease NOS
 G672.00 Hypertensive encephalopathy
 G672.11 Hypertensive crisis
 G673.00 Cerebral aneurysm, nonruptured
 G673000 Dissection of cerebral arteries, nonruptured
 G673100 Carotico-cavernous sinus fistula
 G673200 Carotid artery dissection
 G673300 Vertebral artery dissection
 G674.00 Cerebral arteritis
 G674000 Cerebral amyloid angiopathy

G675.00 Moyamoya disease
 G676.00 Nonpyogenic venous sinus thrombosis
 G676000 Cereb infarct due cerebral venous thrombosis, nonpyogenic
 G677.00 Occlusion/stenosis cerebral arts not result cerebral infarct
 G677000 Occlusion and stenosis of middle cerebral artery
 G677100 Occlusion and stenosis of anterior cerebral artery
 G677200 Occlusion and stenosis of posterior cerebral artery
 G677300 Occlusion and stenosis of cerebellar arteries
 G677400 Occlusion+stenosis of multiple and bilat cerebral arteries
 G678.00 Cereb autosom dominant arteriop subcort infarcts leukoenceph
 G679.00 Small vessel cerebrovascular disease
 G67A.00 Cerebral vein thrombosis
 G67B.00 Reversible cerebral vasoconstriction syndrome
 G67B.11 Call-Fleming syndrome
 G67y.00 Other cerebrovascular disease OS
 G67z.00 Other cerebrovascular disease NOS
 G68..00 Late effects of cerebrovascular disease
 G680.00 Sequelae of subarachnoid haemorrhage
 G681.00 Sequelae of intracerebral haemorrhage
 G682.00 Sequelae of other nontraumatic intracranial haemorrhage
 G683.00 Sequelae of cerebral infarction
 G68W.00 Sequelae/other + unspecified cerebrovascular diseases
 G68X.00 Sequelae of stroke,not specfd as h'morrhage or infarction
 G6y..00 Other specified cerebrovascular disease
 G6z..00 Cerebrovascular disease NOS
 Gyu6.00 [X]Cerebrovascular diseases
 Gyu6000 [X]Subarachnoid haemorrhage from other intracranial arteries
 Gyu6100 [X]Other subarachnoid haemorrhage
 Gyu6200 [X]Other intracerebral haemorrhage
 Gyu6300 [X]Cerebrl infarctn due/unspcf occlusn or sten/cerebrl artr
 Gyu6400 [X]Other cerebral infarction
 Gyu6500 [X]Occlusion and stenosis of other precerebral arteries
 Gyu6600 [X]Occlusion and stenosis of other cerebral arteries
 Gyu6700 [X]Other specified cerebrovascular diseases
 Gyu6C00 [X]Sequelae of stroke;not specfd as h'morrhage or infarction
 Gyu6D00 [X]Sequelae/other unspecified cerebrovascular diseases
 Gyu6E00 [X]Subarachnoid haemorrh from intracranial artery, unspecif
 Gyu6F00 [X]Intracerebral haemorrhage in hemisphere, unspecified
 Gyu6G00 [X]Cereb infarct due unsp occlus/stenos precerebr arteries
 G6W..00 Cereb infarct due unsp occlus/stenos precerebr arteries
 G6X..00 Cerebrl infarctn due/unspcf occlusn or sten/cerebrl artr
 G73z000 Intermittent claudication
 G73z011 Claudication

G73..12 Ischaemia of legs
 G73zz00 Peripheral vascular disease NOS
 G73z.00 Peripheral vascular disease NOS
 G73yz00 Other specified peripheral vascular disease NOS
 G73..11 Peripheral ischaemic vascular disease
 G73..00 Other peripheral vascular disease
 G73..13 Peripheral ischaemia
 2G63.00 Ischaemic toe
 G702.00 Extremity artery atheroma
 G742z00 Peripheral arterial embolism and thrombosis nos
 G702z00 Extremity artery atheroma NOS
 G76A.00 Arterial insufficiency
 G73y100 Peripheral angiopathic disease EC NOS
 R055011 [d]peripheral circulatory failure
 G73y.00 Other specified peripheral vascular disease
 14NB.00 H/O: peripheral vascular disease procedure
 Gyu7400 [X]Other specified peripheral vascular diseases
 7A56600 Percutaneous transluminal placement peripheral stent artery
 G733.00 Ischaemic foot
 G73z012 Vascular claudication
 G734.00 Peripheral arterial disease
 16I..00 Claudication distance

Chronic kidney disease

14D..11 Kidney disease
 1Z10.00 Chronic kidney disease stage 1
 1Z12.00 Chronic kidney disease stage 3
 1Z13.00 Chronic kidney disease stage 4
 1Z14.00 Chronic kidney disease stage 5
 1Z1G.00 Chronic kidney disease stage 3B without proteinuria
 K13z.00 Kidney and ureter disease NOS
 S76..00 Injury to kidney
 S760000 Kidney injury without open wound into cavity, unspecified
 S760z00 Kidney injury without mention of open wound into cavity NOS

Hypoglycaemia

66A6.00 Last hypo. attack
 66A7.00 Frequency of hypo. attacks
 66A7000 Frequency of hospital treated hypoglycaemia
 66A7100 Frequency of GP or paramedic treated hypoglycaemia
 66Ad.00 Hypoglycaemic attack requiring 3rd party assistance
 66Ad000 Hypo atck - atndn ambulan crew
 66AJ200 Loss of hypoglycaemic warning

66AJ300 Recurrent severe hypos
 66AJ400 Hypoglycaemic warning absent
 671F100 Hypoglycaemic management discussed
 679L100 Hypoglycaemia education
 C110.00 Hypoglycaemic coma
 C110.11 Insulin coma
 C110z00 Hypoglycaemic coma NOS
 C112.00 Hypoglycaemia unspecified
 C112000 Reactive hypoglycaemia NOS
 C112100 Spontaneous hypoglycaemia NOS
 C112z00 Hypoglycaemia unspecified NOS
 C116.00 Other hypoglycaemia
 C116000 Post-prandial hypoglycaemia
 C11y100 Drug-induced hypoglycaemia without coma
 Cyu3000 [X]Other hypoglycaemia
 J693000 Post gastrointestinal tract surgery hypoglycaemia
 671F100 Hypoglycaemic management discussed
 679L100 Hypoglycaemia education
 ZV65318 [V]Dietary counselling in hypoglycaemia
 C108E00 Insulin dependent diabetes mellitus with hypoglycaemic coma
 C108E11 Type I diabetes mellitus with hypoglycaemic coma
 C108E12 Type 1 diabetes mellitus with hypoglycaemic coma
 C109D00 Non-insulin dependent diabetes mellitus with hypoglyca coma
 C109D11 Type II diabetes mellitus with hypoglycaemic coma
 C109D12 Type 2 diabetes mellitus with hypoglycaemic coma
 C10EE00 Type 1 diabetes mellitus with hypoglycaemic coma
 C10EE11 Type I diabetes mellitus with hypoglycaemic coma
 C10EE12 Insulin dependent diabetes mellitus with hypoglycaemic coma
 C10FD00 Type 2 diabetes mellitus with hypoglycaemic coma
 C10FD11 Type II diabetes mellitus with hypoglycaemic coma

Ketoacidosis

46Tf.00 Urine ketoacid level
 C101.00 Diabetes mellitus with ketoacidosis
 C101000 Diabetes mellitus, juvenile type, with ketoacidosis
 C101100 Diabetes mellitus, adult onset, with ketoacidosis
 C101y00 Other specified diabetes mellitus with ketoacidosis
 C101z00 Diabetes mellitus NOS with ketoacidosis
 C103.00 Diabetes mellitus with ketoacidotic coma
 C103000 Diabetes mellitus, juvenile type, with ketoacidotic coma
 C103100 Diabetes mellitus, adult onset, with ketoacidotic coma
 C103z00 Diabetes mellitus NOS with ketoacidotic coma
 C10A100 Malnutrition-related diabetes mellitus with ketoacidosis

C10EM00 Type 1 diabetes mellitus with ketoacidosis
C10EM11 Type I diabetes mellitus with ketoacidosis
C10EN00 Type 1 diabetes mellitus with ketoacidotic coma
C10EN11 Type I diabetes mellitus with ketoacidotic coma
C10FN00 Type 2 diabetes mellitus with ketoacidosis
C10FN11 Type II diabetes mellitus with ketoacidosis
C10FP00 Type 2 diabetes mellitus with ketoacidotic coma
C10FP11 Type II diabetes mellitus with ketoacidotic coma
C362600 Metabolic ketoacidaemia
C362700 Ketoacidaemia NEC

Table S2. Data completion rates of type 2 diabetes (T2D) patients who had initiated incretin-based drugs as substitution ('Switch') or add-on ('Add-on') to background sodium-glucose cotransporter-2 inhibitors (SGLT2i) therapy before multiple imputation

| Baseline characteristics | Total (N = 2,888) | Switch (N = 1,461) | Add-on (N = 1,427) |
|---|----------------------|-----------------------|-----------------------|
| Socio-Demographic (% , n) | | | |
| Sex | 100.0% (2,888) | 100.0% (1,461) | 100.0% (1,427) |
| Age | 100.0% (2,888) | 100.0% (1,461) | 100.0% (1,427) |
| Clinical Characteristics (% , n) | | | |
| SBP | 99.8% (2,882) | 99.7% (1,457) | 99.9% (1,425) |
| DBP | 99.8% (2,882) | 99.7% (1,457) | 99.9% (1,425) |
| LDL-C | 90.5% (2,614) | 90.4% (1,321) | 90.6% (1,293) |
| TC/HDL-C Ratio | 97.4% (2,814) | 97.3% (1,422) | 97.5% (1,392) |
| Triglyceride | 94.3% (2,724) | 95.0% (1,388) | 93.6% (1,336) |
| BMI | 98.8% (2,854) | 99.0% (1,446) | 98.7% (1,408) |
| Weight | 98.8% (2,854) | 99.0% (1,446) | 98.7% (1,408) |
| Fasting Glucose | 84.7% (2,446) | 86.8% (1,268) | 82.6% (1,178) |
| HbA1c | 99.7% (2,880) | 99.7% (1,456) | 99.8% (1,424) |
| Creatinine (Serum) | 99.3% (2,869) | 99.1% (1,448) | 99.6% (1,421) |
| eGFR | 99.3% (2,869) | 99.1% (1,448) | 99.6% (1,421) |
| Urine ACR | 77.7% (2,243) | 79.5% (1,162) | 75.8% (1,081) |
| Smoking status | 99.8% (2,883) | 99.9% (1,459) | 99.8% (1,424) |
| Drinking status | 96.5% (2,786) | 97.1% (1,419) | 95.8% (1,367) |
| Charlson's Index [†] | 100.0% (2,888) | 100.0% (1,461) | 100.0% (1,427) |
| Duration of type 2 diabetes | 100.0% (2,888) | 100.0% (1,461) | 100.0% (1,427) |
| Treatment use within 1 year (%) | | | |
| Insulin | 100.0% (2,888) | 100.0% (1,461) | 100.0% (1,427) |
| Basal insulin | 100.0% (2,888) | 100.0% (1,461) | 100.0% (1,427) |
| Oral anti-diabetic drugs | | | |
| Metformin | 100.0% (2,888) | 100.0% (1,461) | 100.0% (1,427) |
| SU | 100.0% (2,888) | 100.0% (1,461) | 100.0% (1,427) |
| TZD | 100.0% (2,888) | 100.0% (1,461) | 100.0% (1,427) |
| Anti-hypertensive drugs | 100.0% (2,888) | 100.0% (1,461) | 100.0% (1,427) |
| ACEI/ARB | 100.0% (2,888) | 100.0% (1,461) | 100.0% (1,427) |
| Lipid-lowering drugs | 100.0% (2,888) | 100.0% (1,461) | 100.0% (1,427) |
| Antiplatelet drugs | 100.0% (2,888) | 100.0% (1,461) | 100.0% (1,427) |
| Anticoagulant | 100.0% (2,888) | 100.0% (1,461) | 100.0% (1,427) |
| Bariatric surgery | 100.0% (2,888) | 100.0% (1,461) | 100.0% (1,427) |
| Duration of SGLT2i | 100.0% (2,888) | 100.0% (1,461) | 100.0% (1,427) |

SBP = systolic blood pressure; DBP = diastolic blood pressure; LDL-C = low-density lipoprotein-cholesterol; TC = total cholesterol; HDL-C = high-density lipoprotein-cholesterol; BMI = body mass index; HbA1c = glycated hemoglobin; eGFR = estimated glomerular filtration rate; urine ACR = urine albumin to creatinine ratio; SU = sulfonylureas; TZD = thiazolidinediones; ACEI = Angiotensin Converting Enzyme Inhibitor; ARB = Angiotensin Receptor Blockers; SGLT2i = sodium-glucose cotransporter-2 inhibitors

Table S3. Subgroup analysis of all-cause mortality, cardiovascular disease, heart failure, and chronic kidney disease.

| Subgroup | All-cause mortality | | | Cardiovascular diseases | | | Heart failure | | | Chronic kidney disease | | |
|-------------------------|---------------------|----------------|---------|-------------------------|----------------|---------|---------------|-----------------|---------|------------------------|----------------|---------|
| | HR | 95% CI | P-value | HR | 95% CI | P-value | HR | 95% CI | P-value | HR | 95% CI | P-value |
| Overall | 0.908 | (0.541, 1.523) | 0.713 | 0.746 | (0.464, 1.198) | 0.225 | 1.238 | (0.501, 3.058) | 0.644 | 1.128 | (0.761, 1.670) | 0.549 |
| GLP-1RA | 0.576 | (0.211, 1.567) | 0.280 | 0.470 | (0.194, 1.143) | 0.096 | 0.446 | (0.080, 2.483) | 0.357 | 1.212 | (0.576, 2.548) | 0.613 |
| DPP4i | 1.084 | (0.590, 1.991) | 0.795 | 0.898 | (0.514, 1.569) | 0.705 | 1.942 | (0.602, 6.270) | 0.267 | 1.094 | (0.691, 1.734) | 0.701 |
| Dapagliflozin | 0.884 | (0.482, 1.622) | 0.691 | 0.828 | (0.471, 1.456) | 0.512 | 1.210 | (0.420, 3.482) | 0.724 | 1.477 | (0.886, 2.462) | 0.134 |
| Empagliflozin | 0.751 | (0.259, 2.176) | 0.597 | 0.621 | (0.222, 1.742) | 0.365 | 1.885 | (0.174, 20.363) | 0.602 | 1.015 | (0.499, 2.065) | 0.967 |
| Exenatide | 0.551 | (0.100, 3.020) | 0.492 | NA | NA | NA | NA | NA | NA | 0.855 | (0.242, 3.012) | 0.807 |
| Liraglutide | 0.723 | (0.166, 3.152) | 0.666 | 0.675 | (0.147, 3.112) | 0.615 | NA | NA | NA | 1.233 | (0.363, 4.190) | 0.737 |
| Sitagliptin | 0.831 | (0.305, 2.270) | 0.718 | 0.623 | (0.275, 1.412) | 0.257 | 0.526 | (0.091, 3.025) | 0.471 | 1.133 | (0.591, 2.172) | 0.707 |
| Linagliptin | 1.521 | (0.594, 3.896) | 0.382 | 0.997 | (0.311, 3.194) | 0.995 | 4.626 | (0.588, 36.377) | 0.145 | 0.997 | (0.419, 2.375) | 0.995 |
| Alogliptin | 1.709 | (0.422, 6.913) | 0.452 | 1.406 | (0.408, 4.844) | 0.589 | NA | NA | NA | 1.393 | (0.353, 5.498) | 0.636 |
| Baseline HbA1c \leq 9 | 0.568 | (0.278, 1.162) | 0.121 | 0.802 | (0.406, 1.583) | 0.525 | 1.421 | (0.404, 5.000) | 0.584 | 1.118 | (0.645, 1.940) | 0.691 |
| Baseline HbA1c $>$ 9 | 1.461 | (0.652, 3.272) | 0.357 | 0.777 | (0.399, 1.514) | 0.459 | 1.124 | (0.312, 4.054) | 0.858 | 1.163 | (0.656, 2.063) | 0.605 |
| Insulin [#] | 1.187 | (0.650, 2.169) | 0.577 | 0.688 | (0.397, 1.192) | 0.182 | 1.720 | (0.540, 5.471) | 0.358 | 1.161 | (0.729, 1.849) | 0.530 |
| Metformin [#] | 0.791 | (0.449, 1.393) | 0.417 | 0.727 | (0.441, 1.200) | 0.213 | 1.120 | (0.448, 2.796) | 0.809 | 1.086 | (0.721, 1.636) | 0.693 |
| SU [#] | 0.877 | (0.406, 1.895) | 0.738 | 0.680 | (0.376, 1.232) | 0.203 | 1.943 | (0.523, 7.224) | 0.321 | 1.197 | (0.683, 2.099) | 0.530 |

GLP1RA = glucagon-like peptide-1 receptor agonists; DPP4i = dipeptidyl peptidase-4 inhibitors; HbA1c = glycated hemoglobin; SU = sulfonylureas; HR = hazard ratio; CI = confidence interval; NA = not applicable

Notes:

* Significant at 0.05 level by Cox proportional hazard regression

Drug use within 1 year prior to baseline

† There was no cardiovascular disease event in the 'Switch' group among exenatide users.

Table S4. Hazard ratio of all-cause mortality, cardiovascular diseases, heart failure, chronic kidney disease, end-stage kidney disease, hypoglycemia, and ketoacidosis events in sensitivity analysis.

| Events | Multiple imputation | | | Complete case with IPTW and trimmed propensity score | | |
|--------------------------|---------------------|-----------------|---------|--|-----------------|---------|
| | HR | 95% CI | P-value | HR | 95% CI | P-value |
| All-cause mortality | 1.041 | (0.635, 1.706) | 0.874 | 1.021 | (0.518, 2.013) | 0.952 |
| Cardiovascular diseases | 0.820 | (0.521, 1.291) | 0.391 | 0.904 | (0.519, 1.574) | 0.722 |
| Heart failure | 1.394 | (0.580, 3.353) | 0.458 | 1.683 | (0.528, 5.364) | 0.379 |
| Chronic kidney disease | 1.260 | (0.864, 1.836) | 0.230 | 0.937 | (0.580, 1.514) | 0.791 |
| End-stage kidney disease | 2.652 | (0.284, 24.755) | 0.392 | 2.080 | (0.219, 19.766) | 0.523 |
| Hypoglycemia | 1.342 | (0.691, 2.607) | 0.385 | 0.808 | (0.347, 1.883) | 0.622 |
| Ketoacidosis | 0.733 | (0.101, 5.326) | 0.759 | 0.215 | (0.021, 2.170) | 0.193 |

| Events | As-treated analysis | | | Competing risk | | |
|--------------------------|---------------------|----------------|---------|----------------|-----------------|---------|
| | HR | 95% CI | P-value | SHR | 95% CI | P-value |
| All-cause mortality | 0.351 | (0.066, 1.873) | 0.220 | | | |
| Cardiovascular diseases | 0.832 | (0.508, 1.363) | 0.465 | 0.751 | (0.467, 1.205) | 0.235 |
| Heart failure | 1.173 | (0.460, 2.992) | 0.738 | 1.248 | (0.506, 3.077) | 0.630 |
| Chronic kidney disease | 1.152 | (0.761, 1.743) | 0.504 | 1.131 | (0.764, 1.675) | 0.537 |
| End-stage kidney disease | NA | NA | NA | 1.949 | (0.205, 18.506) | 0.561 |
| Hypoglycemia | 1.284 | (0.615, 2.683) | 0.505 | 1.182 | (0.596, 2.345) | 0.632 |
| Ketoacidosis | 0.917 | (0.125, 6.737) | 0.932 | 0.867 | (0.114, 6.583) | 0.890 |

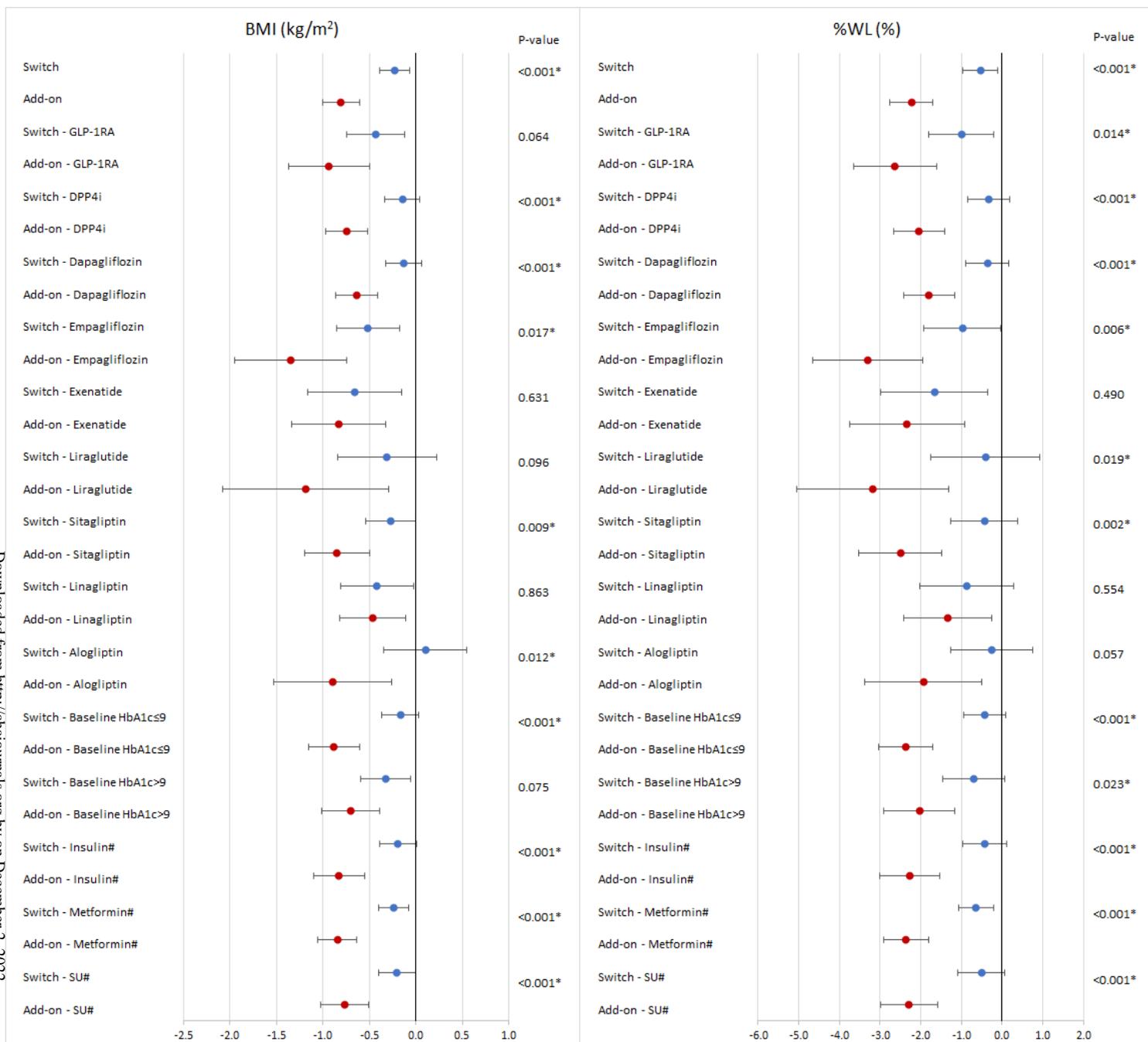
IPTW = inverse probability of treatment weights; HR = hazard ratio; SHR = sub-hazard ratio; CI = confidence interval; NA = not applicable

Notes:

* Significant at 0.05 level by Cox proportional hazard regression

† There was no end-stage kidney disease event observed between baseline and the last date of drug prescription in the ‘Add-on’ group in as-treated analysis.

Figure S1. Mean and 95% confidence interval of 12-month changes in anthropometric and laboratory parameters of type 2 diabetes (T2D) patients who had initiated incretin-based drugs as substitution ('Switch') or add-on ('Add-on') to background sodium-glucose cotransporter-2 inhibitors (SGLT2i) therapy by patient subgroups

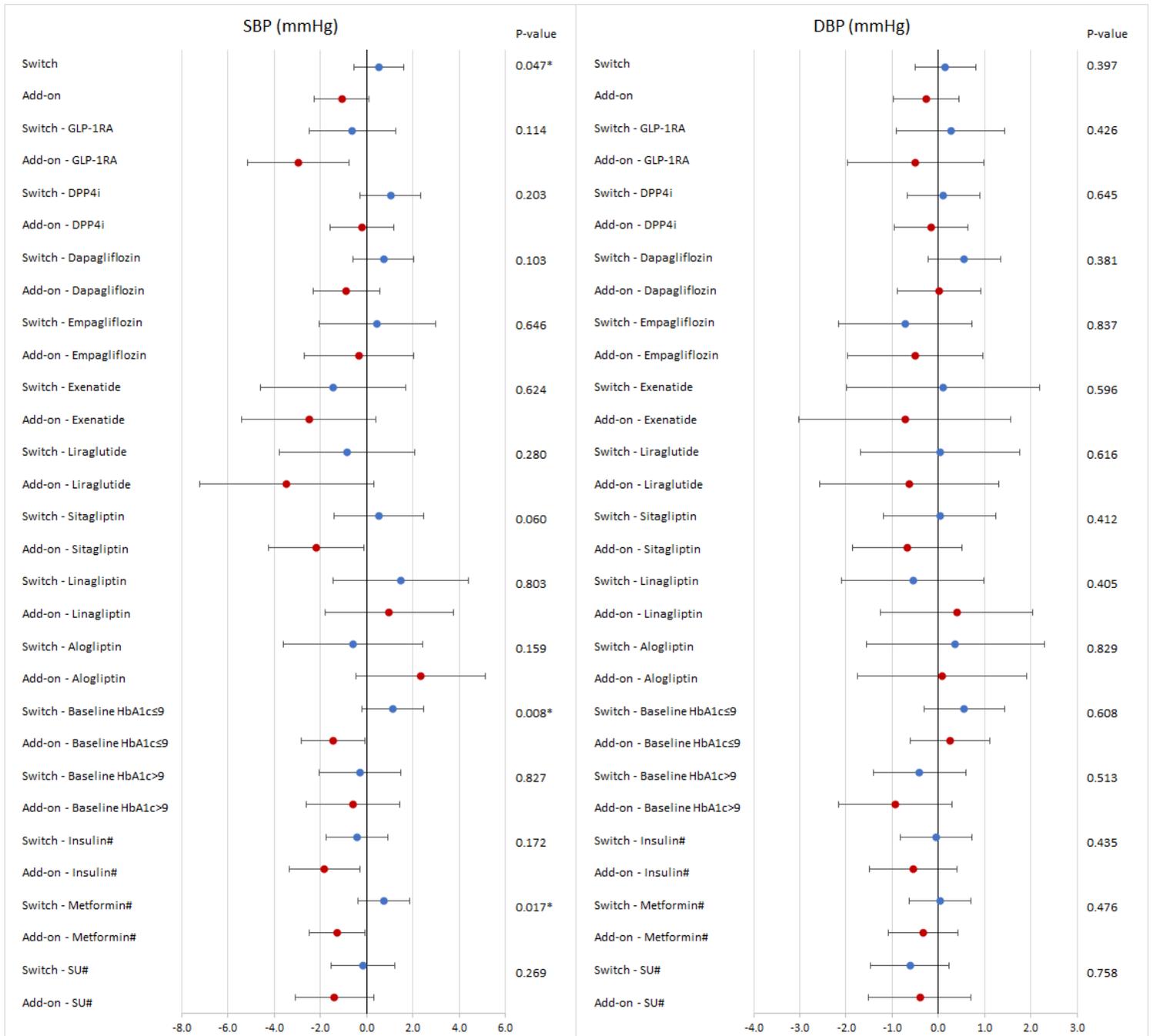


SGLT2i = sodium-glucose cotransporter-2 inhibitors; GLP1RA = glucagon-like peptide-1 receptor agonists; DPP4i = dipeptidyl peptidase-4 inhibitors; BMI = body mass index; %WL = percentage weight loss

Note:

Drug use within 1 year prior to baseline

* Significant difference ($p < 0.05$) in mean of change from baseline to 12-month follow-up between groups by univariate linear regression

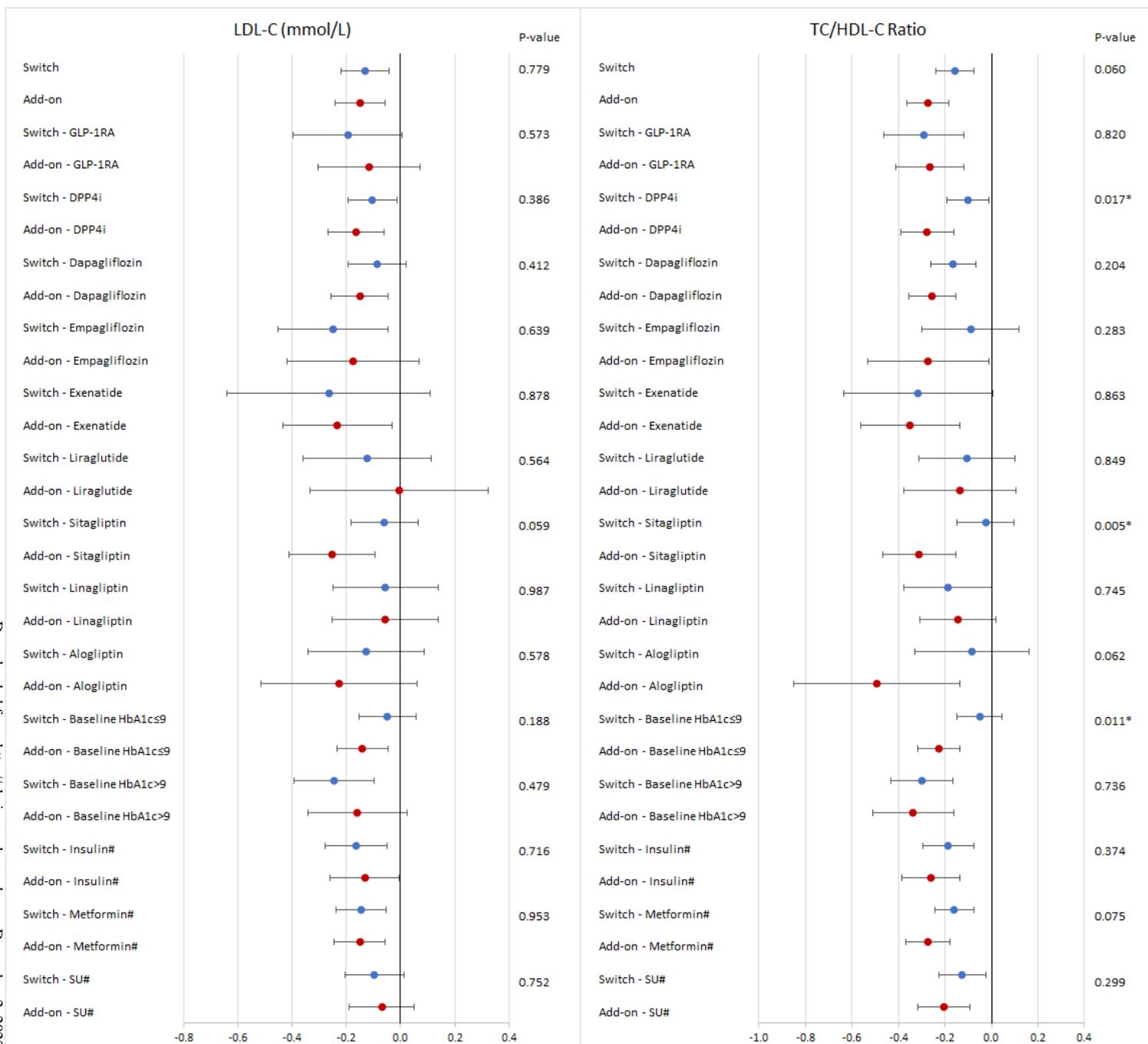


SGLT2i = sodium-glucose cotransporter-2 inhibitors; GLP1RA = glucagon-like peptide-1 receptor agonists; DPP4i = dipeptidyl peptidase-4 inhibitors; SBP = systolic blood pressure; DBP = diastolic blood pressure

Note:

Drug use within 1 year prior to baseline

* Significant difference ($p < 0.05$) in mean of change from baseline to 12-month follow-up between groups by univariate linear regression

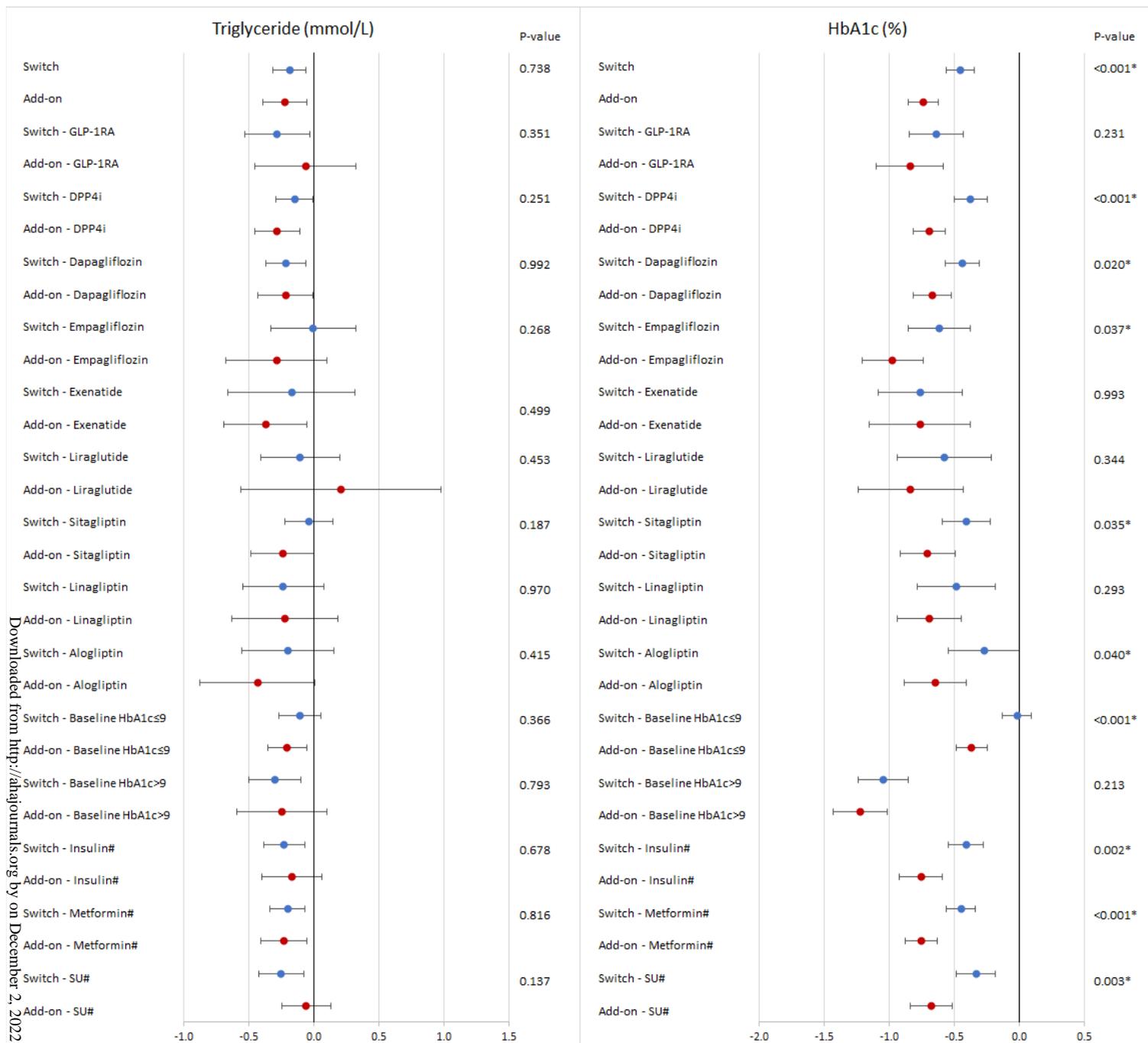


SGLT2i = sodium-glucose cotransporter-2 inhibitors; GLP1RA = glucagon-like peptide-1 receptor agonists; DPP4i = dipeptidyl peptidase-4 inhibitors; LDL-C = low-density lipoprotein-cholesterol; TC = total cholesterol; HDL-C = high-density lipoprotein-cholesterol

Note:

Drug use within 1 year prior to baseline

* Significant difference ($p < 0.05$) in mean of change from baseline to 12-month follow-up between groups by univariate linear regression



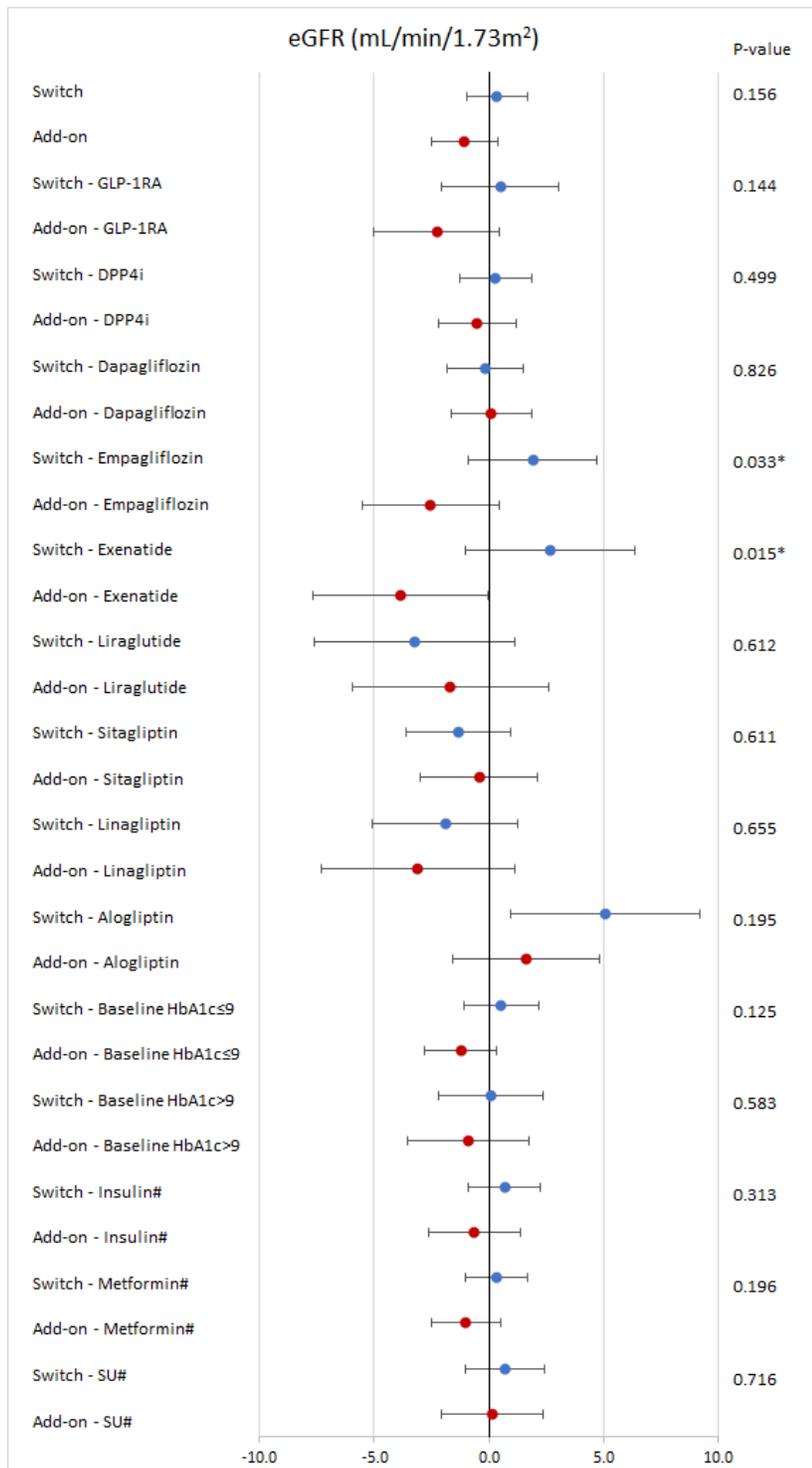
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SGLT2i = sodium-glucose cotransporter-2 inhibitors; GLP1RA = glucagon-like peptide-1 receptor agonists; DPP4i = dipeptidyl peptidase-4 inhibitors; HbA1c = glycated hemoglobin

Note:

Drug use within 1 year prior to baseline

* Significant difference ($p < 0.05$) in mean of change from baseline to 12-month follow-up between groups by univariate linear regression



SGLT2i = sodium-glucose cotransporter-2 inhibitors; GLP1RA = glucagon-like peptide-1 receptor agonists; DPP4i = dipeptidyl peptidase-4 inhibitors; eGFR = estimated glomerular filtration rate

Note:

Drug use within 1 year prior to baseline

* Significant difference ($p < 0.05$) in mean of change from baseline to 12-month follow-up between groups by univariate linear regression