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**SGLT-2 inhibitors in non-alcoholic fatty liver disease patients with type 2 diabetes mellitus: a** **systematic review**

Raj H *et al*. SGLT-2 inhibitors and NAFLD

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**Abstract**

***BACKGROUND***

Non-alcoholic fatty liver disease (NAFLD) is a common comorbidity with type 2 diabetes. The existing therapeutic options for NAFLD are not adequate. Hypocaloric diet and exercise is the cornerstone of therapy in NAFLD. Pioglitazone is the only drug recommended in diabetes patients with biopsy proven non-alcoholic steatohepatitis. The frequent coexistence of NAFLD and type 2 diabetes with their combined adverse health consequences and inadequate therapeutic options makes it necessary to search for newer alternatives.

***AIM***

to assess the effect of sodium glucose cotransporter-2 (SGLT-2) inhibitors on liver enzymes in type 2 diabetes patients with NAFLD.

***METHODS***

We searched PubMed/MEDLINE, Cochrane library, Google scholar, and Clinicaltrials.gov for the relevant articles to be included in this systematic review. Human studies done in type 2 diabetes patients with NAFLD treated with SGLT-2 inhibitors for at least 12 wk were included. Data from eight studies (four randomised controlled trials and four observational studies) were extracted and a narrative synthesis was done. A total of 214 patients were treated with SGLT-2 inhibitors in these studies (94 in randomised controlled trials and 120 in observational studies).

***RESULTS***

The primary outcome measure was change in serum alanine aminotransferase level. Out of eight studies, seven studies showed a significant decrease in serum alanine aminotransferase level. Most of the studies revealed reduction in serum level of other liver enzymes like aspartate aminotransferase and gamma glutamyl transferase. Five studies that reported a change in hepatic fat exhibited a significant reduction in hepatic fat content in those treated with SGLT-2 inhibitors. Likewise, among the three studies that evaluated a change in indices of hepatic fibrosis, two studies revealed a significant improvement in liver fibrosis. Moreover, there was an improvement in obesity, insulin resistance, glycaemia, and lipid parameters in those subjects taking SGLT-2 inhibitors. The studies disclosed that about 17% (30/176) of the subjects taking SGLT-2 inhibitors developed adverse events and more than 40% (10/23) of them had genitourinary tract infections.

***CONCLUSION***

Based on low to moderate quality of evidence,SGLT-2 inhibitors improve the serum level of liver enzymes, liver fat, and liver fibrosis with additional beneficial effects on various metabolic parameters in type 2 diabetes patients with NAFLD.

**Key words:** alanine aminotransferase; Hepatic fat; Hepatic fibrosis; non-alcoholic fatty liver disease; sodium-glucose cotransporter-2 inhibitor; Type 2 diabetes mellitus

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**Core tip:** The frequent coexistence of non-alcoholic fatty liver disease (NAFLD) and type 2 diabetes, their adverse health consequences, and lack of adequate therapeutic options makes it necessary to search for newer alternatives. Currently, pioglitazone and vitamin E are recommended in addition to lifestyle modifications for the management of NAFLD. Animal studies have shown that sodium glucose cotransporter-2 inhibitors might be beneficial in NAFLD present in diabetes patients. The current systematic review shows that sodium glucose cotransporter-2 inhibitors improve the serum level of liver enzymes, liver fat, and liver fibrosis with additional beneficial effects on various metabolic parameters in type 2 diabetes patients with NAFLD.

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**Introduction**

Non-alcoholic fatty liver disease (NAFLD) is an emerging public health issue worldwide. The prevalence of NAFLD in type 2 diabetes mellitus patients is three times greater as compared to the general population. Its prevalence in diabetic subjects ranges from 69%-87% depending upon the imaging modality used[1]. The spectrum of NAFLD includes simple steatosis, steatohepatitis, and cirrhosis[2]. Besides NAFLD is a risk factor for extrahepatic complications like cardiovascular disease, chronic kidney disease, and type 2 diabetes. In addition, the prevalence of both microvascular and macrovascular complications is increased in patients with NAFLD and type 2 diabetes[3].

The existing therapeutic options for NAFLD are not adequate. Hypocaloric diet and exercise is the cornerstone of therapy in NAFLD. Pioglitazone and vitamin E are recommended only in biopsy-proven non-alcoholic steatohepatitis (NASH), but vitamin E is not recommended in diabetic patients due to inadequate evidence[4]. The frequent coexistence of NAFLD and type 2 diabetes with their combined adverse health consequences and inadequate therapeutic options makes it necessary to search for newer alternatives. Based on the information from animal studies, sodium glucose cotransporter-2 (SGLT-2) inhibitors appear promising in the management of NAFLD[5–7]. This systematic review is an effort to review the available literature on the effect of SGLT-2 inhibitors on NAFLD in type 2 diabetes patients.

**MATERIALS AND METHODS**

***Protocol and registration***

This systematic review was performed according to the predefined protocol registered in PROSPERO (Registration ID: CRD42018104572). The protocol can be accessed at the website address https://www.crd.york.ac.uk/prospero. We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis 2009 guidelines for reporting this systematic review[8]. Ethics committee approval was not required for this systematic review because it was done using published data found in the public domain.

***Eligibility criteria***

All observational and randomised controlled trials (RCTs) done using SGLT-2 inhibitors among type 2 diabetes patients with NAFLD having both baseline and post-treatment serum alanine aminotransferase (ALT) level data with a minimum follow-up duration of 12 wk were included in this systematic review. The studies with concomitant pharmacological therapy like pioglitazone or α-tocopherol (vitamin E) for treating NAFLD were excluded to avoid the confounding effects of these drugs on liver function tests. Only those studies that were done in humans and published in English were considered for inclusion. We excluded abstract-only articles, case reports, conference presentations, editorials, reviews, expert opinions, and studies with five participants and less.

***Primary and secondary outcomes***

The primary outcome was the change in serum ALT levels in type 2 diabetes patients with NAFLD treated with SGLT-2 inhibitors.The secondary outcomes were change in serum aspartate aminotransferase (AST) and gamma-glutamyl transferase (GGT) levels, hepatic fat, hepatic fibrosis, metabolic profile, anthropometric parameters, and the adverse effects of SGLT-2 inhibitors.

***Information sources***

PubMed/MEDLINE, Cochrane library, Google scholar, and Clinicaltrials.gov were searched from their date of inception until 31st August, 2018.

***Literature search and study selection***

The search terms/MeSH terms used were “NAFLD”, “Nonalcoholic fatty liver disease”, “Non-alcoholic fatty liver disease”, “Non alcoholic fatty liver disease”, “NASH”, “Non-alcoholic steatohepatitis”, “Nonalcoholic steatohepatitis”, “Non alcoholic steatohepatitis”, “Fatty liver”, “Type 2 diabetes mellitus”, “Type 2 diabetes”, “Diabetes mellitus type 2”, “Diabetes type 2”, “SGLT-2 inhibitors”, “Sodium glucose cotransporter-2 inhibitors”, “SGLT-2”, “SGLT2”, “SGLT 2”, “Canagliflozin”, “Dapagliflozin”, “Empagliflozin”, “Ipragliflozin”, “Luseogliflozin”, “Tofogliflozin”, “Sotagliflozin”, “Remogliflozin”, “Ertugliflozin”, and “Sergliflozin”(table 1). The references of the search articles were scrutinised for relevant articles.

***Data collection process***

The titles and/or abstracts of studies were retrieved using the search strategy and those from additional sources were scrutinised independently by two review authors (HR and JPS) to identify studies that potentially met the inclusion criteria as outlined above. The full texts of these potentially eligible studies were retrieved and independently assessed for eligibility by three review team members (HD, SS, and RP). Any disagreements between the reviewers over the eligibility of particular studies were resolved through discussion with a fourth senior reviewer (SKK). A standardised, pre-formatted excel form was used to extract data from the included studies for the assessment of study quality.

***Data items and synthesis of results***

The extracted data included the author of the study with year, the study methodology, the recruitment and study completion rates, the types of population, the exposure/intervention (dose of SGLT-2 inhibitor, duration), the results (outcome measures like change in serum ALT, AST, GGT, hepatic fat, markers of liver fibrosis, fasting plasma glucose (FPG), glycosylated haemoglobin (HbA1c), lipid profile, homeostasis model assessment-estimated insulin resistance (HOMA-IR), body mass index (BMI), any adverse effects, information for the assessment of the risk of bias, and sources of funding/support.

The statistical review of the study was performed by a biomedical statistician (SSK). A narrative synthesis of the results of individual studies was done. The change in the difference in means and difference in proportions and the respective *P* values as mentioned in the original manuscripts were tabulated and explained in our study.

***Risk of study bias***

The risk of bias of the RCTs was done using Cochrane risk of bias tool[9]. The studies were graded as “good quality” or “fair quality” or “poor quality” according to the level of risk. Methodological Index for Non-Randomized Studies (MINORS) scale was used to assess the risk of bias of observational studies[10]. A study was considered to be an ideal study if the score was 16 for single arm and 24 for comparative studies.

**Results**

***Study selection***

Our literature search from all the aforementioned databases yielded 73 articles. Further articles were obtained from the references of the relevant articles. After eliminating duplicate articles, 55 articles were screened. Eight articles met all of the inclusion criteria (total 214 patients were on SGLT-2 inhibitors) (Figure 1).

***Study characteristics***

The summary of all studies included in this systematic review is given in Tables 2 and 3. Out of the eight studies, four are RCTs[11-14] and four are observational[15-18]. Five studies were conducted amongst the Japanese population. Ipragliflozin was used in three studies whereas canagliflozin and luseogliflozin were used in two studies each, but dapagliflozin and empagliflozin were used in one study each. All studies used one type of SGLT-2 inhibitor except the one authored by Seko *et al*[16], where both canagliflozin and ipragliflozin were used. The change in serum ALT was a secondary outcome while the effect of SGLT- 2 inhibitors on liver fat was the primary outcome in all RCTs.

***Risk of bias within studies***

The risk of bias of RCTs was assessed using the Cochrane risk of bias tool. Among the four RCTs, the studies done by Kuchay *et al*[11] and Eriksson *et al*[14] were of good quality however those done by Ito *et al*[12] and Shibuya *et al*[13] were of fair quality (table 4). The risk of bias of observational studies was assessed using the MINORS scale. All the observational studies were of less than ideal quality (table 5).

***Primary outcome***

**Change in serum ALT levels:** In all of the studies, there was a decrease in serum ALT levels from the baseline in those treated with SGLT-2 inhibitors (Table 6) but in the study done by Shibuya *et al*[13] it did not reach statistical significance.

Kuchay *et al*[11] found a significant decrease in serum ALT levels in the empagliflozin arm compared to the control arm at the end of the study (difference between the two arms was 10.9 IU/L, *P* = 0.005). In the study done by Ito *et al*[12] ALT levels decreased equally in both the groups [Change from baseline in ipragliflozin group: -17.5 (4) and pioglitazone group: -20 (3.4), *P* = 0.642]. Similar results were found in the study by Shibuya *et al*[13] [ΔALT in luseogliflozin arm was 9 (-20, 1) and in metformin are was 4.5 (-5, 9), *P* = 0.064]. Eriksson *et al*[14] found that the ALT reduction in the dapagliflozin arm was more compared to placebo [ΔALT in dapagliflozin arm was -8.24 (8.24) and in the placebo arm was -0.18 (8.82), *P* < 0.05]. Seko *et al*[16] demonstrated that the serum ALT levels in SGLT-2 inhibitor arm was lower compared to the sitagliptin arm at the end of the study [48.8 (5.5) *vs* 71.1 (10), *P* =0.039]

***Secondary outcomes***

**Change in serum AST levels:** Seven of the included studies had data regarding change in serum AST levels (table 7). The study done by Shibuya *et al*[13] did not have data on AST levels. All the studies showed a significant reduction in serum AST levels in those treated with SGLT-2 inhibitors. The decrease in AST with empagliflozin and ipragliflozin was similar compared to placebo and pioglitazone respectively whereas dapagliflozin was better than placebo.

**Change in serum GGT levels:** Seven studies had data regarding GGT levels. Six studies reported a significant decrease in serum GGT levels in those treated with SGLT-2 inhibitors (table 8). In the study done by Seko *et al*[16], there was an insignificant decrease in both the SGLT-2 inhibitor and DPP-4 inhibitor groups. The decrease in GGT with empagliflozin and ipragliflozin was similar compared to placebo and pioglitazone correspondingly while dapagliflozin was better than placebo.

**Change in hepatic fat:** Kuchay *et al*[11] and Eriksson *et al*[14] evaluated hepatic fat using magnetic resonance imaging- derived proton density fat fraction (table 9). It was found that there was a significant reduction in hepatic fat in the empagliflozin arm compared to the control arm in the study done by Kuchay *et al*[11]. In the study done by Eriksson *et al*[14], dapagliflozin or omega-3 carboxylic acid when administered alone or in combination reduced hepatic fat fraction significantly. When compared with placebo, only the combination of both drugs reduced hepatic fat fraction significantly. Sumida *et al*[18] showed that luseogliflozin significantly reduce hepatic fat fraction using magnetic resonance imaging-hepatic fat fraction. Ito *et al*[12] and Shibuya *et al*[13] used liver/spleen attenuation ratio for measuring hepatic fat. They found that ipragliflozin was equivalent to pioglitazone in improving liver/spleen ratio while luseogliflozin was found to be superior to metformin in the same aspect.

***Effect on liver fibrosis indices***

Ito *et al*[12] and Ohki *et al*[15] evaluated liver fibrosis using the FIB-4 index (table 10). There was a significant decrease in the FIB-4 index in the ipragliflozin arms compared to baseline. Ipragliflozin was similar to pioglitazone in decreasing the FIB-4 index. Sumida *et al*[18] used both the FIB-4 index and NAFLD fibrosis score. There was no significant change in either indices.

***Change in metabolic and anthropometric parameters***

Seven studies reported changes in FPG and HbA1c (tables 11 and 12). The majority of the studies showed a decrease in FPG and HbA1c.

In the study done by Ito *et al*[12] there was no difference in the change in HOMA-IR in those treated with either ipragliflozin or pioglitazone (*P =* 0.401) (table 13). There was a significant decrease in HOMA-IR in those treated with dapagliflozin compared to placebo in the study done by Eriksson *et al*[14]. Surprisingly there was an insignificant increase in HOMA-IR in those treated with either a SGLT-2 inhibitor or a gliptin in the study done by Seko *et al*[16].

Six studies included data on the changes in lipid profile (tables 14, 15, and 16). There was a significant decrease in serum thyroglobulin in two studies (Kuchay *et al*[11] and Ito *et al*[12]). Three studies exhibited an increase in high-density lipoprotein cholesterol levels (Ito *et al*[12], Ohki *et al*[15], and Seko *et al*[16]). Most of the studies (Ito *et al*[12], Eriksson *et al*[14], Ohki *et al*[15], Seko *et al*[16], and Sumida *et al*[18]) showed no change in serum LDL levels.

Five studies included BMI change (table 17). There was a reduction in BMI in the SGLT-2 inhibitor arms in all the studies. Empagliflozin was similar to placebo in reducing BMI whereas luseogliflozin was superior to metformin in reducing BMI.

***Adverse effects of SGLT-2 inhibitors***

Out of the eight studies, six studies reported the adverse effects of SGLT-2 inhibitors. There were a total of 30 reported adverse events in 176 patients taking SGLT-2 inhibitors (Table 18). The most common adverse event was genitourinary tract infection (10 events).

**Discussion**

Type 2 diabetes is commonly associated with NAFLD. Serum ALT levels are commonly above the upper limit of normal with AST levels lesser than ALT levels[19]. Animal studies have shown that SGLT-2 inhibitors decrease liver enzymes (ALT, AST), liver weight, and hepatic steatosis[20-23]. There are several mechanisms for improvement in serum liver enzymes in the patients taking SGLT-2 inhibitors. These drugs cause hyperglucagonemia by increasing glucagon secretion from the pancreatic α cells. Glucagon stimulates gluconeogenesis and β-oxidation of fatty acids in the liver via stimulation of peroxisome proliferator-activated receptor alpha and carnitine palmitoyl transferase-1[13]. Thus SGLT-2 inhibitors help to reduce hepatic fat. They reduce collagen deposition and inflammatory cytokine expression in liver[5,22]. They decrease liver enzymes by additionally improving glycaemic parameters and insulin resistance. Out of eight studies, seven showed a decrease in serum ALT and AST levels in our systematic review. Shibuya *et al*[13] observed a decrease in ALT that almost reached statistical significance, however data regarding AST was unavailable[13]. Out of seven studies, six illustrated a significant decrease in GGT levels while in the study by Seko *et al*[16] the change in serum GGT level almost reached statistical significance.

Liver enzymes are surrogate markers of liver histological response, but an improvement in liver histology is not always associated with a decrease in serum liver enzymes[11]. The five studies that evaluated changes in hepatic fat showed a decrease in hepatic fat. There was no correlation of a change in ALT with a change in hepatic fat in the study by Shibuya *et al*[13], however there was a correlation between these two parameters in the study by Sumida *et al*[18]. The decrease in hepatic fat in the SGLT-2 inhibitor arm was comparable to pioglitazone, which is an approved drug for treatment of NAFLD irrespective of the presence of diabetes. Eriksson *et al*[14] observed that although the hepatic fat content decreased in the dapagliflozin arm it did not reach statistical significance compared to placebo[14]. The lesser duration of this study (12 wk) compared to other studies may have contributed to this difference.

The progression of NAFLD to cirrhosis is determined to a large extent by the liver histology. Studies with up to 20 years follow-up have shown that the risk of progression to cirrhosis for simple steatosis, NASH, and NASH with fibrosis are 0%-4%, 25%, and 38%, respectively[24]. The FIB-4 index is a non-invasive tool to assess liver fibrosis[25]. It is calculated from the patient’s age, platelet count, ALT levels, and AST levels. The FIB-4 index was decreased with SGLT-2 inhibitor therapy in two out of three studies. Sumida *et al*[18] used the NAFLD fibrosis score in addition to the FIB-4 index to assess liver fibrosis. The NAFLD fibrosis score is a composite score of six variables (age, BMI, hyperglycaemia, platelet count, albumin, and AST/ALT ratio)[26]. There was no significant change in either indices in this study.

It has been shown that NAFLD is more common in those with poor glycaemic control than those with good glycaemic control[27]. SGLT-2 inhibitors promote glycosuria by inhibiting SGLT-2 in the proximal convoluted tubule. Therefore their action is dependent on blood glucose levels but insulin independent[28]. They cause a significant reduction in FPG[29]. A meta-analysis of RCTs has concluded that the average HbA1c reduction at 52 wk of SGLT-2 inhibitor therapy to be 0.6%[30]. Another meta-analysis has shown that SGLT-2 inhibitor monotherapy is equivalent to metformin monotherapy in reducing HbA1c levels[31]. However, the decrease in HbA1c was more in the luseogliflozin arm compared to the metformin arm in the study by Shibuya *et al*[13]. Four out of seven studies and six out of seven studies showed a decrease in FPG and HbA1c, respectively, in the SGLT-2 inhibitor arm. Thus, the improved glycaemic status is one of the mechanisms by which SGLT-2 inhibitors ameliorate NAFLD.

SGLT-2 inhibitors ameliorate insulin resistance in numerous ways. SGLT-2 inhibitors improve obesity associated insulin resistance by regulating macrophage recruitment and altering the proportion of pro-inflammatory and anti-inflammatory macrophages. They enhance fat utilization by promoting β-oxidation of fatty acids and browning of white adipose tissue by inducing the expression of thermogenin leading to an improvement in the lipid profile. Similar to other antidiabetic drugs, SGLT-2 inhibitors reduce insulin resistance by decreasing glucotoxicity. Dapagliflozin has been shown to improve insulin sensitivity by increasing adiponectin and zinc-A2-glycoprotein levels[32]. Only dapagliflozin was shown to decrease insulin resistance in the study by Eriksson *et al*[14].

SGLT-2 inhibitors caused weight reduction. The major mechanism that causes weight reduction is the decrease in fat mass. The decrease in fat mass is due to the shift in substrate utilization to lipids instead of carbohydrates[33,34]. Ito *et al*[12] and Shibuya *et al*[13] demonstrated that SGLT-2 inhibitors caused a significant reduction in abdominal visceral and subcutaneous fat area as measured by computed tomography scan. Similarly, Eriksson *et al*[14] showed that dapagliflozin significantly reduced abdominal visceral and subcutaneous adipose tissue volume as assessed by magnetic resonance imaging. The other mechanisms of weight loss are the urinary glucose loss which amounts to approximately 200 Kcal/d and osmotic diuresis[33,35]. Unlike the other weight-reducing effects of SGLT-2 inhibitors, which are potentially beneficial, osmotic diuresis is clearly an adverse effect. Seko *et al*[16] showed that ipragliflozin and canagliflozin significantly reduced total body water in addition to body fat mass as measured by bioelectrical impedance analysis. Five studies showed a significant decrease in BMI in patients on SGLT-2 inhibitor therapy. Thus, the major beneficial effects of SGLT-2 inhibitors on NAFLD are exerted via reduction in hepatic fat and fibrosis, improved glycaemic control, decrease in insulin resistance, and weight loss.

The most common adverse effects of SGLT-2 inhibitors are genitourinary tract infections. In addition, they may cause diabetic ketoacidosis, dizziness, acute kidney injury, lower limb amputations, and bone fractures[36,37]. A meta-analysis concluded that there was no difference between placebo and SGLT-2 inhibitors for serious adverse events[38]. Among the 30 adverse events reported in all the studies, the most common was genitourinary tract infections (10 out of 23 characterised events).

The major strength of this systematic review was that the effect of five SGLT-2 inhibitors on NAFLD in patients with type 2 diabetes was evaluated in both RCTs and observational studies. Moreover, liver fat, liver fibrosis, metabolic, and anthropometric parameters in addition to liver enzymes were assessed as outcome variables following SGLT-2 inhibitor therapy. Yet this systematic review has a few limitations. First, most of the studies were done amongst the Japanese population. As a result, the study findings may not be applicable to patients from other ethnicities. Second, the sample size was considerably small and the duration of follow-up was of limited period in most of the studies. Third, the confounding effect of concomitant anti-diabetes drugs like metformin, DPP- 4 inhibitors, and glucagon like peptide-1 analogues on NAFLD cannot be ruled out, particularly in observational studies. Fourth, two studies (Eriksson *et al*[14] and Sumida *et al*[18]) were funded by pharmaceutical companies, which is a source of potential conflicts of interest.

***Summary and conclusion***

In conclusion based on the available evidence, SGLT-2 inhibitors were found to improve serum levels of liver enzymes, liver fibrosis indices, and liver fat without significant side effects in type 2 diabetes patients with NAFLD. They showed additional beneficial effects on obesity, glycaemic parameters, insulin resistance, and dyslipidaemia in these subjects. However, the quality of evidence was low to moderate. Prospective studies, preferably RCTs, comparing different SGLT-2 inhibitors with standard treatments of NAFLD in multi-ethnic populations with a longer follow-up period are needed in the future.

**ARTICLE HIGHLIGHTS**

***Research background***

Non-alcoholic fatty liver disease (NAFLD) is a common comorbidity with type 2 diabetes. The existing therapeutic options for NAFLD are not adequate. Hypocaloric diet and exercise is the cornerstone of therapy in NAFLD. Pioglitazone is the only drug recommended in diabetes patients with biopsy proven non-alcoholic steatohepatitis. The frequent coexistence of NAFLD and type 2 diabetes along with their combined adverse health consequences and inadequate therapeutic options makes it necessary to search for newer alternatives. This systematic review is an effort to review the available literature on the effect of sodium glucose cotransporter-2 (SGLT-2) inhibitors on NAFLD in type 2 diabetes patients.

***Research motivation***

Because the existing therapeutic options are not adequate for NAFLD patients, there is a need for finding newer alternatives. SGLT-2 inhibitors have shown promise in the management of NAFLD in animals. Hence, we reviewed the available literature on the effect of SGLT-2 inhibitors in NAFLD in type 2 diabetes patients. This will promote further high quality research on the effect of SGLT-2 inhibitors in NAFLD.

***Research objectives***

The primary outcome was the change in serum alanine aminotransferase levels in type 2 diabetes patients with NAFLD treated with SGLT-2 inhibitors.The secondary outcomes were change in serum aspartate aminotransferase and gamma-glutamyl transferase levels, hepatic fat, hepatic fibrosis, metabolic profile, anthropometric parameters, and the adverse effects of SGLT-2 inhibitors.

***Research methods***

This systematic review was registered in PROSPERO and performed according to Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines. We searched PubMed/MEDLINE, Cochrane library, Google scholar, and Clinicaltrials.gov for the relevant articles to be included in this systematic review. A narrative synthesis of the results of individual studies was done. The change in the difference in means and difference in proportions and the respective *P* values as mentioned in the original manuscripts were tabulated and explained. The quality of the randomised controlled trials and observational studies was analysed using the Cochrane risk of bias tool and MINORS scale, respectively.

***Research results***

Eight articles (four randomised controlled trials and four observational studies) were included in this systematic review. A total of 214 patients were treated with SGLT-2 inhibitors. SGLT-2 inhibitors caused a significant improvement in liver enzymes, hepatic fat, hepatic fibrosis, glycaemia, insulin resistance, obesity, and lipid parameters with minimal adverse effects. However, the quality of evidence is low to moderate.

***Research conclusions***

We found that SGLT-2 inhibitors improved the serum levels of liver enzymes, liver fat, and liver fibrosis with additional beneficial effects on various metabolic and anthropometric parameters in type 2 diabetes patients with NAFLD. However, the number of patients treated with SGLT-2 inhibitors was small. The findings of this systematic review will have impact in choosing anti-diabetes medication like SGLT-2 inhibitors to treat NAFLD associated with type 2 diabetes.

***Research perspectives***

The studies included in this systematic review were heterogeneous with regard to study design and intervention drugs. Most of the studies were done amongst the Japanese population. Prospective studies, preferably randomised controlled trials, comparing different SGLT-2 inhibitors with standard treatments of NAFLD in multi-ethnic populations with a longer follow-up period are needed in the future.

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**Specialty type:** Endocrinology and metabolism

**Country of origin:** India

**Peer-review report classification**

Grade A (Excellent): 0

Grade B (Very good): 0

Grade C (Good): C, C, C

Grade D (Fair): 0

Grade E (Poor): 0

Identification

Articles identified:

PubMed (*n* = 42)

Cochrane library (*n* = 6)

Google scholar (*n* = 6)

Clinicaltrials.gov (*n* = 7)

Additional records from article references

(*n* = 12)

Records after removal of duplicates

(*n* = 55)

Screening

Excluded based on title and abstract:

Not relevant = 15

Review = 7

Systematic reviews/ meta-analysis = 1

Animal studies = 13

Case reports = 2

Recruiting = 3

Conference = 1

Not published = 1

Records screened

(*n* = 55)

Eligibility

1. One article excluded because of concomitant vitamin E use

2. One article was excluded because of concomitant pioglitazone use and insufficient data

3. One article was excluded because NAFLD definition was not based on imaging/biopsy

4. One article was excluded because of sample size (n=5)

Full text articles assessed for eligibility

(*n* = 12)

Inclusion

Total articles included

(*n* = 8)

**Figure 1 Literature search and study selection.**

**Table 1 Randomised controlled trials**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **S. No** | **Ref.** | **Inclusion criteria** | **Age (yr)** | **Male gender** | **Intervention arm** | **Control arm** | **Follow-up duration** | **Primary outcome** |
| 1 | Kuchay *et al*[11], 2018 | Age > 20 yr, hepatic  steatosis (MRI-PDFF> 6%),  HbA1c > 7.0% to < 10.0% | Intervention arm: 50.7 (12.8)  Control arm: 49.1 (10.3) | Intervention arm: 16 (64%)  Control arm: 17 (68%) | Standard treatment + Empagliflozin 10 mg daily (*n =* 25) | Standard treatment  (*n =* 25) | 20 wk | Change in liver fat content by MRI-PDFF |
| 2 | Ito *et al*[12], 2017 | Age 20-75 yr, HbA1c 7.0–11.0%, BMI < 45 kg/m2, On diet and exercise therapy alone or with oral hypoglycaemic agents other than SGLT-23 inhibitors and thiazolidinediones and/or insulin, NAFLD, findings suggesting hepatic steatosis and hepatic dysfunction on clinical laboratory tests or on imaging studies (*e.g.*, computed tomography or ultrasound) | Pioglitazone arm: 59.1 (9.8)  Ipragliflozin arm: 57.3 (12.1) | Pioglitazone arm: 18 (53%)  Ipragliflozin arm: 14 (44%) | Ipragliflozin 50 mg daily (*n =* 32) | Pioglitazone 15-30 mg daily  (*n =* 34) | 24 wk | Change in L/S attenuation ratio |
| 3 | Shibuya *et al*[13] , 2018 | Fatty liver diagnosed on the basis of computed tomography or abdominal sonography, HbA1c 6.0%–10.0%, age 20–70 yr | Luseogliflozin arm: 51 (47-62)  Metformin arm: 60 (53-66) | Luseogliflozin arm: 10 (62.5%)  Metformin arm: 8 (50%) | Luseogliflozin 2.5 mg daily (*n =* 16) | Metformin 1.5 g daily (*n =* 16) | 24 wk | Change in L/S attenuation ratio |
| 4. | Eriksson *et al*[14], 2018 | Age 40–75 yr, treated with a stable dose of metformin or sulfonylurea alone or in combination for at least 3 mo, MRI-PDFF > 5.5%, BMI 25–40 kg/m2 | Dapagliflozin arm: 65 (6.5)  Omega 3-carboxylic acid arm: 66.2 (5.9)  O + D arm: 65(5.4)  Placebo arm: 65.6 (6.1) | Dapagliflozin arm: 16 (76.2%)  Omega 3-carboxylic acid arm: 11 (55%)  O + D arm: 15 (68.2%)  Placebo arm: 17 (81%) | Dapagliflozin 10 mg daily (*n =* 21) or Omega 3- carboxylic acid 4 g daily (*n =* 20) or Combination (*n =* 22) | Placebo (*n =* 21) | 12 wk | Change in liver fat content by MRI-PDFF |

MRI-PDFF: Magnetic resonance imaging-derived proton density fat fraction; L/S: Liver/spleen; O + D: Omega 3-carboxylic acid + Dapagliflozin; SGLT-2: Sodium glucose cotransporter-2; NAFLD: Non-alcoholic fatty liver disease.

**table 2 Literature search strategy**

|  |  |
| --- | --- |
| **S. No** | **Search terms** |
| 1 | NAFLD |
| 2 | Nonalcoholic fatty liver disease |
| 3 | Non-alcoholic fatty liver disease |
| 4 | Non alcoholic fatty liver disease |
| 5 | NASH |
| 6 | Non-alcoholic steatohepatitis |
| 7 | Nonalcoholic steatohepatitis |
| 8 | Non alcoholic steatohepatitis |
| 9 | Fatty liver |
| 10 | 1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7 OR 8 OR 9 |
| 11 | Type 2 diabetes mellitus |
| 12 | Type 2 diabetes |
| 13 | Diabetes mellitus type 2 |
| 14 | Diabetes type 2 |
| 15 | 11 OR 12 OR 13 OR 14 |
| 16 | SGLT-2 inhibitors |
| 17 | Sodium glucose cotransporter-2 inhibitors |
| 18 | SGLT-2 |
| 19 | SGLT2 |
| 20 | SGLT 2 |
| 21 | Canagliflozin |
| 22 | Dapagliflozin |
| 23 | Empagliflozin |
| 24 | Ipragliflozin |
| 25 | Luseogliflozin |
| 26 | Tofogliflozin |
| 27 | Sotagliflozin |
| 28 | Remogliflozin |
| 29 | Ertugliflozin |
| 30 | Sergliflozin |
| 31 | 16 OR 17 OR 18 OR 19 OR 20 OR 21 OR 22 OR 23 OR 24 OR 25 OR 26 OR 27 OR 28 OR 29 OR 30 |
| 32 | 10 AND 15 AND 31 |

NAFLD: Non-alcoholic fatty liver disease; SGLT-2: Sodium glucose cotransporter-2.

**Table 3 Observational studies**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **S. No** | **Ref.** | **Design** | **Inclusion criteria** | **Age (yr)** | **Male gender** | **Sample size** | **SGLT-2 inhibitor** | **Follow-up duration** |
| 1 | Ohki *et al*[15],  2016 | Prospective study | Type 2 diabetes with NAFLD treated with GLP-1analogues or DPP-4 inhibitors and failed to normalise serum ALT levels | 54.2 (49.3-60.1) | 19 (79.2%) | 24 | Ipragliflozin 25-50 mg daily | 320 d (302-329) |
| 2 | Seko *et al*[16],2016 | Retrospective cohort study | Type 2 diabetes with NAFLD | SGLT-2 inhibitor arm: 60.3 (1.8)  Sitagliptin arm: 59.4 (3.7) | SGLT-2 inhibitor arm: 9 (37.5%)  Sitagliptin arm: 8 (38.1%) | 24  (SGLT-2 inhibitor); 21 (Sitagliptin ) | Canagliflozin 100 mg (*n =* 18) or Ipragliflozin 50 mg daily  (*n =*  6) | 24 wk |
| 3 | Gautam *et al*[17], 2018 | Prospective study | Type 2 diabetes with NAFLD | - | - | 32 | Canagliflozin 100 mg daily | 24 wk |
| 4 | Sumida *et al*[18], 2018 | Prospective study | Age > 20 yr, HbA1c > 6.5% to < 8.5%, NAFLD | 55.4 (13.6) | 28 (70%) | 40 | Luseogliflozin 2.5 mg daily | 24 wk |

NAFLD: Non-alcoholic fatty liver disease; SGLT-2: Sodium glucose cotransporter-2; GLP-1: Glucagon like peptide-1; DPP-4: Dipeptidyl peptidase-4.

**table 4 Assessment of study quality of randomised controlled trials**

|  |  |  |  |
| --- | --- | --- | --- |
| **Study** | **Criteria** | **Risk of bias** | **Study quality** |
| Kuchay *et al*[11] | Random sequence generation | Low risk | Good quality |
| Allocation concealment | Low risk |
| Selective reporting | Low risk |
| Other bias | Low risk |
| Blinding of participants and personnel | Low risk |
| Blinding of outcome assessment | Low risk |
| Incomplete outcome data | Low risk |
| Ito *et al*[12] | Random sequence generation | Low risk | Fair quality |
| Allocation concealment | Unclear risk |
| Selective reporting | Low risk |
| Other bias | Low risk |
| Blinding of participants and personnel | Low risk |
| Blinding of outcome assessment | Low risk |
| Incomplete outcome data | Low risk |
| Shibuya *et al*[13] | Random sequence generation | Unclear risk | Fair quality |
| Allocation concealment | Unclear risk |
| Selective reporting | Low risk |
| Other bias | Low risk |
| Blinding of participants and personnel | Low risk |
| Blinding of outcome assessment | Low risk |
| Incomplete outcome data | Low risk |
| Eriksson *et al*[14] | Random sequence generation | Low risk | Good quality |
| Allocation concealment | Low risk |
| Selective reporting | Low risk |
| Other bias | Low risk |
| Blinding of participants and personnel | Low risk |
| Blinding of outcome assessment | Low risk |
| Incomplete outcome data | Low risk |

**table 5 Assessment of study quality of observational studies**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **S. No** | **Criteria** | **Ohki *et al*[15]** | **Seko *et al*[16]** | **Gautam *et al*[17]** | **Sumida *et al*[18]** |
| 1 | A clearly stated aim | 2 | 2 | 2 | 2 |
| 2 | Inclusion of consecutive patients | 0 | 2 | 2 | 1 |
| 3 | Prospective collection of data | 2 | 0 | 2 | 2 |
| 4 | Endpoints appropriate to the aim of the study | 2 | 2 | 2 | 2 |
| 5 | Unbiased assessment of the study endpoint | 0 | 0 | 0 | 0 |
| 6 | Follow-up period appropriate to the aim of the study | 2 | 2 | 2 | 2 |
| 7 | Loss to follow up less than 5% | 2 | 2 | 2 | 2 |
| 8 | Prospective calculation of the study size | 0 | 0 | 0 | 0 |
| 9 | An adequate control group | NA | 0 | NA | NA |
| 10 | Contemporary groups | NA | 2 | NA | NA |
| 11 | Baseline equivalence of groups | NA | 2 | NA | NA |
| 12 | Adequate statistical analyses | NA | 2 | NA | NA |
| 13 | Total score | 10/16 | 16/24 | 12/16 | 11/16 |

**table 6 Change in serum aspartate aminotransferase levels in individual studies**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study** | **Serum AST levels (U/L)** | | | ***P* value** | ***P* value between groups** |
| **Group** | **Baseline** | **Study completion** |
| Kuchay *et al*[11] | Empagliflozin | 44.6 (23.5) | 36.2 (9.0) | 0.04 | 0.212 |
| Control | 45.3 (24.3) | 44.6 (23.8) | 0.931 |
| Ito *et al*[12] | Ipragliflozin | 39.7 (16.7) | 27.3 (8.9) | < 0.05 | 0.802 |
| Pioglitazone | 43.3 (20.5) | 32.4 (15.4) | < 0.05 |
| Eriksson *et al*[14] | Placebo | 29.4 (13.2) | -1.2 (7.2)1 | - | Non-significant |
| Omega-3 CA | 30.6 (10.2) | +4.8 (9.0)1 | - | Non-significant2 |
| Dapagliflozin | 31.2 (11.4) | -4.2 (5.4)1 | - | < 0.052 |
| O + D | 30 (10.2) | +1.2 (5.4)1 | - | Non-significant2 |
| Ohki *et al*[15] | Ipragliflozin | 37 (29.0-52.0) | 28 (23.0-31.0) | 0.03 | - |
| Seko *et al*[16] | SGLT-2 inhibitor | 54.4 (5.6) | 38 (3.1) | 0.001 | - |
| Sitagliptin | 67 (7.7) | 52.5 (7.7) | 0.016 |  |
| Gautam *et al*[17] | Canagliflozin | 72 (16.7) | 53 (10.3) | 0.00001 | - |
| Sumida *et al*[18] | Luseogliflozin | 40.7 (22.2) | 31.9 (18.2) | < 0.001 | - |

1Change from baseline; 2Compared to placebo. AST: Aspartate aminotransferase; CA: carboxylic acid; O + D: Omega-3 carboxylic acid + Dapagliflozin; SGLT-2: Sodium glucose cotransporter-2.

**Table 7 Change in serum alanine aminotransferase levels in individual studies**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study** | **Serum ALT level (U/L)** | | | ***P* value** | ***P* value between groups** |
| **Group** | **Baseline** | **Study completion** |
| Kuchay *et al*[11] | Empagliflozin | 64.3 (20.2) | 49.7 (25.8) | 0.001 | 0.005 |
| Control | 65.3 (40.3) | 61.6 (38.4) | 0.422 |
| Ito *et al*[12] | Ipragliflozin | 57.4 (27.3) | 38.2 (20.5) | < 0.05 | 0.642 |
| Pioglitazone | 53.1 (26.6) | 36.8 (15.1) | < 0.05 |
| Shibuya *et al*[13] | Luseogliflozin | 49.5 (31.0, 70.0) | 31 (26.0, 55.0) | 0.057 | 0.064 |
| Metformin | 39 (23.0, 56.0) | 39 (27.0, 51.0) | 0.518 |
| Eriksson *et al*[14] | Placebo | 33.53 (12.4) | -0.2 (8.8)1 | - | Non-significant |
| Omega-3 C | 37.65 (14.7) | +5.9 (16.5)1 | - | Non-significant2 |
| Dapagliflozin | 39.41 (14.7) | -8.2 (8.2)1 | - | < 0.052 |
| O + D | 35.88 (17.1) | +0.1 (12.9)1 | - | Non-significant2 |
| Ohki *et al*[15] | Ipragliflozin | 62 (43.0-75.0) | 38.0 (31.0-65.0) | 0.01 | - |
| Seko *et al*[16] | SGLT-2 inhibitor | 70.8 (8.1) | 48.8 (5.5) | 0.002 | 0.039 |
| Sitagliptin | 92.4 (11.2) | 71.1 (10.0) | 0.012 |
| Gautam *et al*[17] | Canagliflozin | 96 (18.7) | 60.0 (17.6) | 0.00001 | - |
| Sumida *et al*[18] | Luseogliflozin | 54.7 (28.2) | 42.4 (26.5) | < 0.001 | - |

1Change from baseline; 2Compared to placebo. ALT: Alanine aminotransferase; CA: carboxylic acid; O + D: Omega-3 carboxylic acid + Dapagliflozin; SGLT-2: Sodium glucose cotransporter-2.

**table 8 Change in serum gamma-glutamyl transferase levels in individual studies**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study** | **Serum GGT (IU/L )** | | | ***P* value** | ***P* value between groups** |
| **Group** | **Baseline** | **Study completion** |
| Kuchay *et al*[11] | Empagliflozin | 65.8 (36.1) | 50.9 (24.6) | 0.002 | 0.057 |
| Control | 63.9 (45.3) | 60.0 (39.0) | 0.421 |
| Ito *et al*[12] | Ipragliflozin | 62.8 (58.3) | 44.0 (38.3) | < 0.05 | 0.642 |
| Pioglitazone | 71.6 (54.1) | 48.8 (61.2) | < 0.05 |
| Eriksson *et al*[14] | Placebo | 32.4 (17.4) | +2.4 (9.6)1 | - | Non-significant |
| Omega-3 CA | 54.0 (57.6) | +2.4 (12.0)1 | - | Non-significant2 |
| Dapagliflozin | 58.2 (43.2) | -4.8 (13.8)1 | - | < 0.052 |
| O + D | 40.2 (14.4) | -0.6 (13.8)1 | - | Non-significant2 |
| Ohki *et al*[15] | Ipragliflozin | 75.0 (47.0-105.0) | 60.0 (40.0-101.0) | 0.03 | - |
| Seko *et al*[16] | SGLT-2 inhibitor | 61.7 (9.1) | 58.7 (11.5) | 0.051 | - |
| Sitagliptin | 89.2 (11.8) | 82.4 (11.9) | 0.36 |
| Gautam *et al*[17] | Canagliflozin | 75.1 (31.8) | 69.2 (26.2) | 0.003 | - |
| Sumida *et al*[18] | Luseogliflozin | 62.4 (77.1) | 48.2 (56.3) | 0.003 | - |

1Change from baseline; 2Compared to placebo. CA: carboxylic acid; GGT: Gamma-glutamyl transferase;O + D: Omega-3 carboxylic acid + Dapagliflozin; SGLT-2: Sodium glucose cotransporter-2.

**table 9 Change in hepatic fat in individual studies**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Study** | **Parameter** | **Group** | **Baseline** | **Study completion** | ***P* value** | ***P* value between groups** |
| Kuchay *et al*[11] | MRI-PDFF | Empagliflozin | 16.2 (7) | 11.3 (5.3) | < 0.0001 | < 0.0001 |
| Control | 16.4 (7.3) | 15.5 (6.7) | 0.054 |
| Ito *et al*[12] | L/S ratio | Ipragliflozin | 0.8 (0.2) | 1.0 (0.2) | < 0.05 | 0.90 |
| Pioglitazone | 0.8 (0.3) | 1.0 (0.2) | < 0.05 |
| Shibuya *et al*[13] | L/S ratio | Luseogliflozin | 0.9 (0.6-1.0) | 1.0 (0.8-1.2) | 0.0008 | 0.00002 |
| Metformin | 1.0 (0.8-1.1) | 0.9 (0.7-1.0) | 0.017 |
| Eriksson *et al*[14] | MRI-PDFF | Placebo | 15.1 (6.5) | -0.6 (1.9)1 | - | Non-significant |
| Omega-3 CA | 22.2 (11.0) | -3.2 (2.9)1 | - | Non-significant2 |
| Dapagliflozin | 17.3 (9.1) | -2.2 (3.3)1 | - | Non-significant2 |
| O + D | 17.8 (9.2) | -3.2 (3.5)1 | - | < 0.052 |
| Sumida *et al*[18] | MRI-HFF | Luseogliflozin | 21.5 (7.2) | 15.7 (6.8) | < 0.001 | - |

1Change from baseline; 2 Compared to placebo. MRI-PDFF: Magnetic resonance imaging-derived proton density fat fraction; L/S ratio: Liver/spleen attenuation ratio; MRI-HFF: Magnetic resonance imaging-hepatic fat fraction; CA: Carboxylic acid; O + D: Omega-3 CA + Dapagliflozin arm.

**table 10 Assessment of liver fibrosis in individual studies**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Study** | **Parameter** | **Group** | **Baseline** | **Study completion** | ***P* value** | ***P* value between groups** |
| Ito *et al*[12] | FIB-4 index | Ipragliflozin | 1.44 (0.64) | 1.22 (0.55) | < 0.05 | 0.596 |
| Pioglitazone | 1.84 (1.13) | 1.71 (1.19) | Non-significant |
| Ohki *et al*[15] | FIB-4 index | Ipragliflozin | 1.75 (0.82-1.93) | 1.39 (0.77-1.99) | 0.04 | - |
| Sumida *et al*[18] | FIB-4 index | Luseogliflozin | 1.63 (1.19) | 1.52 (0.92) | 0.17 | - |
| NAFLD fibrosis score | Luseogliflozin | 1.61 (0.71) | 1.62 (0.88) | 0.86 | - |

FIB:Fibrosis 4; NAFLD: Non-alcoholic fatty liver disease.

**table 11 Change in fasting plasma glucose in individual studies**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study** | **Fasting plasma glucose (mg/dl)** | | | ***P* value** | ***P* value between groups** |
| **Group** | **Baseline** | **Study completion** |
| Kuchay *et al*[11] | Empagliflozin | 173.0 (44.0) | 124.0 (17.0) | < 0.001 | 0.85 |
| Control | 176.0 (57.0) | 120.0 (19.0) | < 0.0001 |
| Ito *et al*[12] | Ipragliflozin | 160.1 (38.7) | 136.5 (26.7) | < 0.05 | 0.785 |
| Pioglitazone | 169.4 (50.9) | 139.0 (26.6) | < 0.05 |
| Shibuya *et al*[13] | Luseogliflozin | 127.0 (116.0, 136.0) | 125.0 (113.0, 138.0) | 0.87 | 0.583 |
| Metformin | 147.0 (126.0, 161.0) | 134.0 (122.0, 145.0) | 0.32 |
| Eriksson *et al*[14] | Placebo | 169.2 (29.7) | +6.7 (14.8)1 | - | Non-significant |
| Omega-3 CAa | 162.4 (26.6) | +3.8 (19.3)1 | - | Non-significant2 |
| Dapagliflozin | 161.8 (33.3) | -17.6 (26.8)1 | - | < 0.052 |
| O + Db | 168.8 (35.5) | -16.4 (36.0)1 | - | < 0.052 |
| Ohki *et al*[15] | Ipragliflozin | 162.0 (135.0-189.0) | 135.0 (120.0-166.0) | 0.3 | - |
| Seko *et al*[16] | SGLT-2c inhibitor | 125.0 (6.0) | 116.6 (4.2) | 0.07 | Non-significant |
| Sitagliptin | 114.6 (7.0) | 134.0 (10.5) | 0.067 |
| Sumida *et al*[18] | Luseogliflozin | 142.0 (30.3) | 135.4 (25.6) | 0.009 | - |

1Change from baseline; 2Compared to placebo. CA: carboxylic acid; O + D: Omega-3 carboxylic acid + Dapagliflozin; SGLT-2: Sodium glucose cotransporter-2.

**table 12 Change in glycosylated haemoglobin in individual studies**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study** | **Glycosylated haemoglobin (%)** | | | ***P* value** | ***P* value between groups** |
| **Group** | **Baseline** | **Study completion** |
| Kuchay *et al*[11] | Empagliflozin | 9.0 (1.0) | 7.2 (0.6) | < 0.001 | 0.88 |
| Control | 9.1 (1.4) | 7.1 (0.9) | < 0.0001 |
| Ito *et al*[12] | Ipragliflozin | 8.5 (1.5) | 7.6 (1.0) | < 0.05 | 0.522 |
| Pioglitazone | 8.3 (1.4) | 7.1 (0.9) | < 0.05 |
| Shibuya *et al*[13] | Luseogliflozin | 7.8 (7.2, 7.9) | 6.5 (6.4, 7.0) | 0.002 | 0.023 |
| Metformin | 7.4 (6.9, 7.7) | 7.3 (6.7, 7.6) | 0.362 |
| Eriksson *et al*[14] | Placebo | 7.4 (0.8) | -0.1 (0.4)1 | - | Non-significant |
| Omega-3 CAa | 7.4 (0.7) | +0.1 (0.4)1 | - | Non-significant2 |
| Dapagliflozin | 7.4 (0.6) | -0.6 (0.7)1 | - | < 0.052 |
| O + Db | 7.5 (0.8) | -0.5 (0.5)1 | - | Non-significant2 |
| Ohki *et al*[15] | Ipragliflozin | 8.4 (7.8-8.9) | 7.6 (6.9-8.2) | < 0.01 | - |
| Seko *et al*[16] | SGLT-2c inhibitor | 6.7 (0.1) | 6.5 (0.1) | 0.055 | Non-significant |
| Sitagliptin | 7.0 (0.3) | 6.9 (0.3) | 0.331 |
| Sumida *et al*[18] | Luseogliflozin | 7.3 (0.7) | 7.0 (0.7) | 0.002 | - |

1Change from baseline; 2Compared to placebo.CA: carboxylic acid; O + D: Omega-3 carboxylic acid + Dapagliflozin; SGLT-2: Sodium glucose cotransporter-2.

**table 13 Change in homeostasis model assessment-estimated insulin resistance in individual studies**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study** | **HOMA-IR** | | | ***P* value** | ***P* value between groups** |
| **Group** | **Baseline** | **Study completion** |
| Ito *et al*[12] | Ipragliflozin | 5.2 (2.5) | 4.8 (5.5) | Non-significant | 0.401 |
| Pioglitazone | 5.7 (3.4) | 4.5 (2.7) | < 0.05 |
| Eriksson *et al*[14] | Placebo | 4.2 (2.4) | -0.2 (1.4)1 | - | Non-significant |
| Omega 3-CA | 5.4 (2.9) | +0.3 (2.4)1 | - | Non-significant2 |
| Dapagliflozin | 4.3 (1.9) | -1.1 (1.4)1 | - | < 0.052 |
| O + D | 4.4 (1.7) | -0.9 (1.6)1 | - | < 0.052 |
| Seko *et al*[16] | SGLT-2 inhibitor | 4.5 (0.5) | 7.9 (2.3) | 0.955 | - |
| Sitagliptin | 4.4 (0.5) | 6.5 (0.8) | 0.163 |

1Change from baseline; 2 Compared to placebo.HOMA-IR: homeostasis model assessment-estimated insulin resistance; CA: carboxylic acid; O + D: Omega-3 carboxylic acid + Dapagliflozin; SGLT-2: Sodium glucose cotransporter-2.

**table 14 Change in serum triglycerides in individual studies**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study** | **Serum triglycerides (mg/dl)** | | | ***P* value** | ***P* value between groups** |
| **Group** | **Baseline** | **Study completion** |
| Kuchay *et al*[11] | Empagliflozin | 201.0 (124.0) | 155.0 (52.0) | 0.01 | 0.678 |
| Control | 212.0 (115.0) | 175.0 (43.0) | 0.019 |
| Ito *et al*[12] | Ipragliflozin | 166.9 (76.4) | 143.4 (81.4) | < 0.05 | 0.938 |
| Pioglitazone | 188.4 (148.8) | 169.3 (131.3) | Non-significant |
| Eriksson *et al*[14] | Placebo | 169.2 (84.1) | -11.5 (45.6)1 | - | Non-significant |
| Omega-3 CA | 186.9 (81.5) | -15.9 (47.4)1 | - | Non-significant2 |
| Dapagliflozin | 178.0 (103.6) | +14.2 (40.5)1 | - | Non-significant2 |
| O + D | 168.3 (72.6) | -25.7 (57.1)1 | - | Non-significant2 |
| Ohki *et al*[15] | Ipragliflozin | 148.0 (107.0, 222.) | 145.0 (114.0, 172.0) | 0.75 | - |
| Seko *et al*[16] | SGLT-2 inhibitor | 153.8 (15.9) | 137.8 (10.5) | 0.236 | - |
| Sitagliptin | 193.4 (25.2) | 191.1 (23.8) | 0.986 |
| Sumida *et al*[18] | Luseogliflozin | 158.1 (110.5) | 129.4 (59.5) | 0.062 | - |

1Change from baseline; 2Compared to placebo. CA: carboxylic acid; O + D: Omega-3 carboxylic acid + Dapagliflozin; SGLT-2: Sodium glucose cotransporter-2.

**table 15 Change in serum low-density lipoprotein cholesterol in individual studies**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study** | **Serum low-density lipoprotein cholesterol (mg/dl)** | | | ***P* value** | ***P* value between groups** |
| **Group** | **Baseline** | **Study completion** |
| Kuchay *et al*[11] | Empagliflozin | 112.0 (35.0) | 95.0 (22.0) | 0.018 | 0.512 |
| Control | 114.0 (30.0) | 96.0 (17.0) | 0.001 |
| Ito *et al*[12] | Ipragliflozin | 108.3 (36.2) | 110.7 (40.1) | Non-significant | 0.057 |
| Pioglitazone | 104.0 (27.9) | 114.6 (29.5) | < 0.05 |
| Eriksson *et al*[14] | Placebo | 98.2 (34.4) | +1.6 (15.5)1 | - | Non-significant |
| Omega-3 CA | 111.8 (34.4) | +2.3 (17.4)1 | - | Non-significant2 |
| Dapagliflozin | 109.4 (34.8) | +7.7 (20.5)1 | - | Non-significant2 |
| O + D | 88.9 (23.2) | +5.8 (21.7)1 | - | Non-significant2 |
| Ohki *et al*[15] | Ipragliflozin | 113.0 (89.0-142.0) | 103.0 (92.0-122.0) | 0.08 | - |
| Seko *et al*[16] | SGLT-2inhibitor | 119.2 (5.8) | 119.8 (5.7) | 0.943 | - |
| Sitagliptin | 112.9 (4.9) | 127.1 (8.8) | 0.063 |
| Sumida *et al*[18] | Luseogliflozin | 101.0 (22.4) | 105.0 (24.4) | 0.11 | - |

1Change from baseline; 2Compared to placebo. CA: carboxylic acid; O + D: Omega-3 carboxylic acid + Dapagliflozin; SGLT-2: Sodium glucose cotransporter-2.

**table 16 Change in serum high-density lipoprotein cholesterol in individual studies**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study** | **Serum high-density lipoprotein cholesterol (mg/dl)** | | | ***P* value** | ***P* value between groups** |
| **Group** | **Baseline** | **Study completion** |
| Kuchay *et al*[11] | Empagliflozin | 42.0 (12.0) | 45.0 (12.0) | 0.087 | 0.752 |
| Control | 45.0 (15.0) | 47.0 (12.0) | 0.097 |
| Ito *et al*[12] | Ipragliflozin | 48.9 (9.3) | 54.7 (10.4) | < 0.05 | 0.82 |
| Pioglitazone | 47.4 (11.6) | 52.7 (13.5) | < 0.05 |
| Eriksson *et al*[14] | Placebo | 51.4 (14.9) | -0.4 (5.0)1 | - | Non-significant |
| Omega-3 CA | 49.9 (14.1) | +0.4 (3.2)1 | - | Non-significant2 |
| Dapagliflozin | 49.9 (9.5) | +0.4 (4.8)1 | - | Non-significant2 |
| O + D | 51.4 (10.2) | +1.6 (5.0)1 | - | Non-significant2 |
| Ohki *et al*[15] | Ipragliflozin | 42.0 (40.0-50.0) | 44.0 (42.0-59.0) | 0.01 | - |
| Seko *et al*[16] | SGLT-2 inhibitor | 53.9 (2.5) | 55.4 (2.6) | 0.043 | - |
| Sitagliptin | 54.8 (3.3) | 55.6 (2.3) | 0.531 |
| Sumida *et al*[18] | Luseogliflozin | 55.6 (11.7) | 57.5 (13.4) | 0.062 | - |

1Change from baseline; 2Compared to placebo. CA: carboxylic acid; O + D: Omega-3 carboxylic acid + Dapagliflozin; SGLT-2: Sodium glucose cotransporter-2.

**table 17 Change in body mass index in individual studies**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study** | **Body mass index (kg/m2)** | | | ***P* value** | ***P* value between groups** |
| **Group** | **Baseline** | **Study completion** |
| Kuchay *et al*[11] | Empagliflozin | 30.0 (3.8) | 28.7 (3.5) | 0.001 | 0.124 |
| Control | 29.4 (3.1) | 28.8 (2.8) | 0.019 |
| Shibuya *et al*[13] | Luseogliflozin | 27.9 (26.2, 28.7) | 27.0 (25.6, 28.3) | 0.002 | 0.031 |
| Metformin | 27.2 (24.8, 32.1) | 27.3 (24.3, 31.6) | 0.646 |
| Ohki *et al*[15] | Ipragliflozin | 30.1 (26.1-31.4) | 27.6 (25.3-30.2) | < 0.01 | - |
| Seko *et al*[16] | SGLT-2 inhibitor | 29.6 (0.7) | 28.3 (0.7) | < 0.001 | - |
| Sitagliptin | 29.2 (1.5) | 28.9 (1.4) | 0.295 |
| Sumida *et al*[18] | Luseogliflozin | 27.8 (3.6) | 27.2 (1.0) | < 0.001 | - |

SGLT-2: Sodium glucose cotransporter-2.

**Table 18 Adverse effects of sodium glucose cotransporter-2 inhibitors in individual studies**

|  |  |  |  |
| --- | --- | --- | --- |
| **Study** | **No. of adverse events** | **No. of patients** | **Types of adverse events** |
| Kuchay *et al*[11] | 3 | 25 | Nonspecific fatigue: 1  Arthralgia: 1  Balanoposthitis: 1 |
| Ito *et al*[12] | 9 | 32 | UTI: 3  Increased appetite: 2  Nausea: 1  Headache: 1  Diarrhoea: 1  Vaginal candidiasis: 1 |
| Eriksson *et al*[14] | 7 | 21 | - |
| Seko *et al*[16] | 2 | 26 | UTI: 2 |
| Gautam *et al*[17] | 1 | 32 | Recurrent UTI with genital candidiasis: 1 |
| Sumida *et al*[18] | 8 | 40 | Low blood pressure: 3  Vaginal itching: 2  Constipation: 1  Vertigo: 1  Dehydration: 1 |
| Total | 30 | 176 | Most common adverse event: Genitourinary tract infections-10 |

UTI: Urinary tract infection.