BMJ Open  Glycaemic durability with dipeptidyl peptidase-4 inhibitors in type 2 diabetes: a systematic review and meta-analysis of long-term randomised controlled trials

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ABSTRACT

Objectives: To evaluate glycaemic durability with dipeptidyl peptidase-4 (DPP-4) inhibitors in type 2 diabetes.

Design: A systematic review and meta-analysis of long-term randomised trials of DPP-4 inhibitors on haemoglobin A1c (HbA1c) was conducted. Electronic searches were carried out on the following databases: MEDLINE, EMBASE, Scopus and Web of Knowledge to December 2013. Searches were supplemented by a review of trial registries and references from identified trials. Trials were included if they lasted at least 76 weeks, and had intermediate and final assessments of HbA1c. Citations and full-text articles were screened by two reviewers. A random effect model was used to pool data.

Participants: Adults with type 2 diabetes.

Interventions: Any DPP-4 inhibitor (sitagliptin, vildagliptin, saxagliptin, linagliptin and alogliptin).

Outcome measures: The difference between final and intermediate HbA1c assessment was the primary outcome.

Results: We screened 461 citations and reviewed 12 articles reporting 12 trials in 14 829 participants. All trials were of 76 weeks duration at least. The difference in HbA1c changes between final and intermediate points averaged 0.22% (95% CI 0.15% to 0.29%), with high heterogeneity ($I^2$=91%, $p<0.0001$). Estimates of differences were not affected by the analysis of six extension trials (0.24%, 0.02 to 0.46), or five trials in which a DPP-4 inhibitor was added to metformin (0.24%, 0.16 to 0.32).

Conclusions: There is evidence that the effect of DPP-4 inhibitors on HbA1c in type 2 diabetes significantly declines during the second year of treatment. Future research should focus on the characteristics of patients that benefit most from DPP-4 inhibitors in terms of glycaemic durability.

INTRODUCTION

The optimal drug sequence after metformin failure is an area of uncertainty. Sulfonylureas are the most commonly added oral antidiabetic drugs in this scenario; the dipeptidyl-peptidase 4 (DPP-4) inhibitors may offer a non-inferior glucose-lowering efficacy, with a reduced risk of hypoglycaemia and weight gain. Moreover, DPP-4 inhibitors may protect pancreatic β-cells from enhanced apoptosis in animal models of diabetes, and also improve several markers of β-cell function in type 2 diabetes. Intuitively, a positive influence of DPP-4 inhibitors on islet function may attenuate the inherently progressive nature of β-cell loss.

We hypothesised that durability of glycaemic control may be a surrogate marker to test the hypothesis that DPP-4 inhibitors influence β-cell loss: randomised trials evaluating the long-term (up to 108 weeks) effect of DPP-4 inhibitors on haemoglobin A1c (HbA1c) level are available and may be used as an indicator of glycaemic durability.

METHODS

Eligibility criteria

We followed the PRISMA (Preferred Reporting Items for Systematic reviews and
Meta-Analyses) checklist for reporting systematic reviews and meta-analyses.\textsuperscript{7} We carried out this systematic review in accordance with the study protocol (see online supplementary appendix 1). Peer-reviewed journal articles and conference abstracts that reported the results of a randomised controlled trial and met the following eligibility criteria were eligible for inclusion: (1) trials reporting the effect of DPP-4 inhibitors (sitagliptin, vildagliptin, saxagliptin, linagliptin, alogliptin) on the HbA1c level in participants with type 2 diabetes who were either drug naïve, or on background therapy with metformin or other oral agents; (2) lasting at least 76 weeks and (3) having final and intermediate assessment of HbA1c, with the intermediate point assessed between 24 and 52 weeks. We have shown that the relation between the HbA1c response to DPP-4 inhibitors and time is quite linear until between 24 and 52 weeks.\textsuperscript{8} We included primary trials and extension trials. We excluded trials if the intervention included the initiation of two agents at the same time, and the doses of DPP-4 inhibitors were different from those approved in the clinical practice (sitagliptin, 100 mg once daily; vildagliptin, 50 mg twice daily; saxagliptin, 5 mg once daily; linagliptin, 5 mg once daily; alogliptin, 25 mg once daily). The search had no language restriction; however, we excluded reviews, editorials, comments, letters and abstracts.

**Search strategy**

We performed an electronic search for randomised trials evaluating DPP-4 inhibitors in patients with type 2 diabetes through December 2013. We searched MEDLINE, EMBASE, Scopus and Web of Knowledge using the following terms as Medical Subject Heading and keywords: type 2 diabetes (T2DM, NIDDM, non-insulin-dependent diabetes), glycated haemoglobin (haemoglobin A1c, HbA1c, A1C), DPP-4 inhibitors (sitagliptin, vildagliptin, saxagliptin, linagliptin, alogliptin), clinical trials. We searched for additional trials in the prescribing information documents of approved medications, at relevant web sites (eg, http://www.clinicaltrialresults.org and http://www.clinicaltrials.gov), and in personal reference lists of recovered articles.

**Study selection, data extraction and quality assessment**

The relevance of studies was assessed with a hierarchical approach on the basis of title, abstract and the full manuscript. Two reviewers (KE and DG) independently screened the titles and abstracts of identified citations to select those requiring full-text assessment. Where there was disagreement, a third reviewer (MIM) assessed the records to reach a consensus. Full-text articles were further assessed and data were entered into a prespecified table that included information on authors, year of publication, sample size, type of DPP-4 inhibitor, duration of follow-up, comparator drug, baseline HbA1c and outcomes. Of the selected trials, only study arms assessing the efficacy of DPP-4 inhibitors were included in the analysis, whereas any other arm (placebo or comparator drug) of the same trial was excluded.

**Data analysis**

We used the Cochrane Collaboration’s tool to assess risk of bias at the outcome level.\textsuperscript{9} Bias was assessed in duplicate with disagreements resolved by a third reviewer. The assessed domains were random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment and completeness of outcome data. We used the difference between decrease of HbA1c from baseline at the end of follow-up (76–104 weeks) versus A1C decrease at intermediate assessments (24–52 weeks) during DPP-4 inhibitor administration as an index of glycaemic durability. The difference between final and intermediate HbA1c assessment was the primary end point. To calculate the overall difference between the two periods, each study was weighted by the reciprocal of the variance for HbA1c change. In a conservative approach, the random-effect estimates of mean differences, which allow for variation of true effects across studies, were taken as ‘main results’. Because variations for HbA1c change between final and intermediate end points were not directly reported, they were calculated by assuming a correlation coefficient of 0.5. A sensitivity analysis was performed assuming a correlation of 0.25 and 0.75; subgroup analyses were also performed for primary trials, extension trials and ‘add-on’ metformin trials. Heterogeneity between studies was assessed by using $Q$ statistic and $I^2$.\textsuperscript{10} A $p$ value of $Q$ statistic less than 0.10 was considered significant. Data were analysed using Stata, V.11.0 (Stata Corp., College Station, Texas, USA).

**RESULTS**

A total of 751 citations were identified (figure 1) from electronic searches. A further 11 relevant publications were identified as cited by included trial reports. After removing duplicates, we screened 461 citations. Based on the title and abstract, 447 were assessed as ineligible. The full text of the remaining 14 articles was assessed for eligibility. Further assessment of these articles revealed that two did not meet the inclusion criteria, one because the dose of saxagliptin was twofold higher than the recommended 5 mg daily dose,\textsuperscript{11} and the other because the intermediate Hb1c assessment occurred at 12 weeks.\textsuperscript{12}

**Duration and settings**

A total of 12 articles were eligible for inclusion.\textsuperscript{13–24} All studies were randomised controlled trials (table 1); most trials were multinational and sponsored by industry. The trials were published between 2008 and 2013. Six trials\textsuperscript{19–24} were an extension of previous randomised trials (table 1). All trials were double blind, including the six extension trials.

**Intervention**

All trials assessed the effect of a DPP-4 inhibitor versus placebo or a comparator drug on HbA1c level in...
patients with type 2 diabetes. In five trials,\textsuperscript{14–16, 20–24} the DPP-4 inhibitor was added to ongoing metformin treatment; in three trials, the patients were either drug naive\textsuperscript{13, 19} or suspended the previous treatment\textsuperscript{21}; in the remaining four trials, the DPP-4 inhibitor was added to glyburide,\textsuperscript{22} a thiazolidinedione\textsuperscript{23} or to a multiple\textsuperscript{17} or variable\textsuperscript{18} antidiabetic therapy.

**Outcomes**

All trials included a definition of the primary outcome, which was the change in HbA1c from baseline to the end of the follow-up in 10 trials.\textsuperscript{13–16, 19–24}

**Risk of bias**

All trials were deemed to have a low risk of selection bias (random sequence generation) and most trials were assessed as having a low risk of attrition bias (figure 2). Most trials provided incomplete information on allocation concealment, blinding of participants and personnel, and blinding of outcome assessment.

**Primary outcome**

Trial findings are summarised in table 2. The difference in HbA1c changes between final and intermediate points averaged 0.22% (95% CI 0.15% to 0.29%, p<0.0001). There was substantial heterogeneity between the results of trials included in the pooled analysis of the primary outcome ($\chi^2$ test for heterogeneity, p<0.0001; $I^2=91\%$).

Sensitivity analysis assuming lower (0.25) or higher (0.75) correlation coefficients of variance did not change results (0.21% and 0.22%, respectively, p<0.0001). Subgroup analyses evaluated whether differences existed between primary or extension studies, or if the addition of the DPP-4 inhibitor to metformin behaved differently from the other studies. Estimates of differences were not significantly affected by the analysis of the six extension trials (0.24%, 0.02 to 0.46, p=0.036), or the five trials in which the DPP-4 inhibitor was added to metformin (0.24%, 0.16 to 0.32, p<0.0001; table 2).

**DISCUSSION**

Declining $\beta$-cell function is the predominant reason for deterioration in glucose tolerance and largely explains the difficulty in maintaining target levels of HbA1c with traditional glucose-lowering agents. The idea that DPP-4 inhibitors may alleviate $\beta$-cell death in animal models seems still attractive\textsuperscript{5} and potentially may be associated
### Table 1 Characteristics of trials included in the analysis

| Author, year and reference | Patients' number | Type of DPP-4 inhibitors | Follow-up weeks | Comparator drug | Add-on to | Baseline HbA1c % (mmol/mol) | ΔHbA1c (%) T1: 24–52 weeks | ΔHbA1c (%) T2: 76–104 weeks | Difference (%) T2−T1: 95% CI |
|----------------------------|------------------|--------------------------|------------------|----------------|-----------|-----------------------------|-----------------------------|----------------------------|--------------------------------|
| Foley, 2009<sup>13</sup>   | 409              | Vilda                    | 104              | Gliclazide     | Naive     | 8.5 (69)                    | −0.9                        | −0.5                       | 0.4 (0.20 to 0.58)          |
| Matthews, 2010<sup>14</sup>| 1051             | Vilda                    | 104              | Glimipiride    | Metformin | 7.3 (56)                    | −0.25                       | −0.1                       | 0.15 (0.11 to 0.19)         |
| Seck, 2010<sup>15</sup>   | 248              | Sita                     | 104              | Glipizide     | Metformin | 7.3 (56)                    | −0.8                        | −0.5                       | 0.26 (0.17 to 0.35)         |
| Gallwitz, 2012<sup>16</sup>| 764              | Lina                     | 104              | Glimipiride    | Metformin | 7.7 (61)                    | −0.38                       | −0.16                      | 0.22 (0.16 to 0.28)         |
| Scirce, 2013<sup>17</sup>| 8280             | Saxa                     | 108              | Placebo       | Variable  | 8.0 (64)                    | −0.4                        | −0.3                       | 0.10 (0.08 to 0.26)         |
| White, 2013<sup>18</sup>  | 2701             | Alo                      | 76               | Placebo       | Multiple   | 8.0 (64)                    | −0.5                        | −0.33                      | 0.17 (0.08 to 0.26)         |
| Goke, 2008<sup>19</sup>   | 305              | Vilda                    | 104              | Metformin     | Naive     | 8.4 (68)                    | −1.0                        | −1.0                       | 0 (−0.17 to 0.17)           |
| Rosenstock, 2009<sup>20</sup>| 354             | Saxa                     | 104              | Rosiglitazone | Metformin | 8.6 (70)                    | −1.1                        | −0.82                      | 0.28 (0.09 to 0.47)         |
| Williams-Herman, 2010<sup>21</sup>| 52             | Sita                     | 104              | Metformin     | None      | 8.5 (69)                    | −1.53                       | −1.2                       | 0.33 (−0.06 to 0.72)        |
| Chacra, 2011<sup>22</sup> | 56               | Saxa                     | 76               | Glyburide     | Glyburide | 8.5 (69)                    | −0.64                       | 0.03                       | 0.67 (0.50 to 0.84)         |
| Hollander, 2011<sup>23</sup>| 186             | Saxa                     | 76               | Placebo       | Thiazo    | 8.4 (68)                    | −0.94                       | −1.09                      | −0.15 (−0.31 to 0.01)       |
| Goke, 2013<sup>24</sup>   | 423              | Saxa                     | 104              | Glipizide     | Metformin | 7.65 (60)                   | −0.74                       | −0.41                      | 0.33 (0.26 to 0.40)         |

Six trials (19–24) are extension studies; Δ, difference from baseline.

*Note:* T1, follow-up at 24–52 weeks; T2, follow-up at 76–104 weeks; 95% CI, 95% confidence interval.
**Table 2** Sensitivity and subgroup analyses

| Pooled differences | Number of arms | Mean age (years)* | Mean basal HbA1c (%)* | T2–T1 HbA1c (%) (95% CI) | p Value | I² (%) | p value |
|--------------------|----------------|------------------|------------------------|--------------------------|---------|-------|---------|
| Correlation 0.50   | 12             | 62.2             | 7.96                   | 0.22 (0.15 to 0.29)       | <0.0001 | 91    | <0.0001 |
| Correlation 0.25   | 12             | 62.2             | 7.96                   | 0.21 (0.14 to 0.29)       | <0.0001 | 86    | <0.0001 |
| Correlation 0.75   | 12             | 62.2             | 7.96                   | 0.22 (0.15 to 0.29)       | <0.0001 | 95    | <0.0001 |
| Primary studies†   | 6              | 63               | 7.93                   | 0.19 (0.13 to 0.25)       | <0.0001 | 86    | <0.0001 |
| Extension studies† | 6              | 54.8             | 8.22                   | 0.24 (0.02 to 0.46)       | 0.036   | 92    | <0.0001 |
| Metformin (add-on to)† | 5          | 57.8             | 7.62                   | 0.24 (0.16 to 0.32)       | <0.0001 | 82    | <0.0001 |

*Mean value weighted by sample size.
†Assuming a 0.50 correlation.

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**Competing interests** KE and DG received consultancy fees, attended advisory boards or have held lectures for a number of pharmaceutical companies producing antidiabetic drugs.

**Patient consent** Obtained.

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Data sharing statement** No additional data are available.

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Protocol for the systematic literature search.

• Broad question 1: Is the antihyperglycaemic effect of DPP-4 inhibitors sustained over time?

• Specific question 1: Did trials assess glycaemic durability with DPP-4 inhibitors? The answer to this specific point was sought by searching trials that had glycaemic durability with DPP-4 inhibitors as main or secondary outcome.

• Specific question 2: in the absence of the durability outcome, which is the best way to assess durability of glycaemic control with DPP-4 inhibitors? The answer to this specific question was sought by searching trials with long follow up (at least 76 weeks) and serial measurements of haemoglobin A1c during the trial.

• Specific question 3: How can the antihyperglycaemic effect of DPP-4 inhibitor be quantified in function of time? The answer to this specific question was sought by using the difference between decrease of HbA1c from baseline at the end of follow-up (76-104 weeks) versus A1C decrease at intermediate assessments (24-52 weeks) during DPP-4 inhibitor administration as an index of glycaemic durability. The difference between final and intermediate HbA1c assessment was the primary endpoint.

The review followed the outlines of PICO (study characteristics):

1. Population: the population to be included in the review consisted of subjects with type 2 diabetes at baseline

2. Exposure: different DPP-4 inhibitors (sitagliptin, vildagliptin, saxagliptin, linagliptin, alogliptin).

3. Comparisons: HbA1c decrease at the end of follow up (second year of treatment) versus HbA1c decrease at an intermediate point (first year of treatment).

4. Outcomes: the difference between final and intermediate HbA1c assessment was the primary endpoint.

Published articles were considered eligible for this review: randomized controlled trials