New Drugs in Development for the Treatment of Diabetes

The number of agents available to improve glycemic control in patients with diabetes has increased substantially in recent years. Only 15 years ago, available therapies included only sulfonylureas and insulin. Today, products from multiple additional classes, offering multiple new mechanisms and enhanced opportunities for combination therapy, have substantially increased the ability to individually tailor therapy for any given patient. And development of new products for the treatment of diabetes continues.

Many new drugs are currently in development for the treatment of diabetes, including more products with new mechanisms. This article will provide a brief overview of some of these drugs. Table 1 lists drugs in development for type 1 or type 2 diabetes by class. Table 2 lists additional drugs with unique mechanisms of action.1–3 Drugs with applications submitted for U.S. Food and Drug Administration (FDA) approval and drugs currently in phase 3 clinical trials are summarized below.

Dipeptidyl Peptidase 4 (DPP-4) Inhibitors

The DPP-4 inhibitors are incretin enhancers. DPP-4 inhibitors are thought to work by slowing the inactivation of the incretin hormones glucagon-like peptide-1 (GLP-1) and glucose-dependent insulinotropic peptide. These agents are released by the gastrointestinal tract in response to food and are involved with the stimulation of glucose-dependent insulin secretion. By inhibiting their inactivation, these drugs prolong the effects of these incretin hormones.

The DPP-4 inhibitors have been assessed as monotherapy and in conjunction with insulin, metformin, sulfonylureas, and thiazolidinediones in patients with type 2 diabetes. Although the DPP-4 inhibitors have been shown to improve glycemic control, as with most other new agents used in the treatment of diabetes, data have not been published addressing the effects of the DPP-4 inhibitors on key outcome measures such as mortality, diabetes complications, or health-related quality of life.4

Most of the DPP-4 inhibitors are structurally distinct. Alogliptin is a quinazolinone-based compound, linagliptin is a xanthine derivative, saxagliptin is a hydroxyadamantyl compound, sitagliptin is a triazolepyrazine compound, and vildagliptin and saxagliptin are pyrrolidine-carbonitrile compounds. The first marketed DPP-4 inhibitor was sitagliptin, which was approved by the FDA in 2006. Applications for approval have also been submitted for alogliptin, saxagliptin, and vildagliptin. Dutogliptin and linagliptin are in phase 3 studies, and numerous additional DPP-4 inhibitors are in phase 2 studies (Table 1). Vildagliptin received an approvable letter from the FDA in 2007 for the treatment of diabetes; however, the FDA approvable letter requested additional data on the safety and efficacy of vildagliptin in renally impaired patients. Vildagliptin is currently available in 18 countries and...
<table>
<thead>
<tr>
<th>Generic/Code Name</th>
<th>Manufacturer</th>
<th>Indication</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DPP-4 Inhibitors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alogliptin/SYR-322</td>
<td>Takeda</td>
<td>Type 2 diabetes</td>
<td>NDA submitted</td>
</tr>
<tr>
<td>AMG 222/ALS2-0426</td>
<td>Amgen/Servier</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>Dutogliptin/PHX1149</td>
<td>Phenomix/Forest Laboratories</td>
<td>Type 2 diabetes</td>
<td>3</td>
</tr>
<tr>
<td>KRP-204/N-5984</td>
<td>Kyorin</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>KRP-104</td>
<td>Kyorin/ActivX Biosciences</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>Linagliptin/BI-1356</td>
<td>Boehringer Ingelheim</td>
<td>Type 2 diabetes</td>
<td>3</td>
</tr>
<tr>
<td>Melogliptin/GRC 8200</td>
<td>Glenmark Pharmaceuticals</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>MP-513</td>
<td>Mitsubishi Tanabe Pharma</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>PF 734200</td>
<td>Pfizer</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>R1579</td>
<td>Roche/Chugai</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>Saxagliptin/BMS-477118</td>
<td>Bristol-Myers Squibb/AstraZeneca</td>
<td>Type 2 diabetes</td>
<td>NDA submitted</td>
</tr>
<tr>
<td>SYR 472</td>
<td>Takeda</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>TA-6666</td>
<td>Mitsubishi Tanabe</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>Vildagliptin</td>
<td>Novartis</td>
<td>Type 2 diabetes</td>
<td>NDA submitted</td>
</tr>
<tr>
<td><strong>GLP-1 Analogs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Albilglutide/GSK716155</td>
<td>GSK</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>AVE0010/ZP-10</td>
<td>Sanofi-Aventis</td>
<td>Type 2 diabetes</td>
<td>3</td>
</tr>
<tr>
<td>CJC-1134-PC/PC-DAC: Exendin-4</td>
<td>ConjuChem</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>Exenatide LAR</td>
<td>Amylin/Alkermes/Lilly</td>
<td>Type 2 diabetes</td>
<td>3</td>
</tr>
<tr>
<td>Liraglutide/NN2211</td>
<td>Novo Nordisk</td>
<td>Type 2 diabetes</td>
<td>NDA submitted</td>
</tr>
<tr>
<td>LY 2189265</td>
<td>Lilly</td>
<td>Type 2 diabetes</td>
<td>3</td>
</tr>
<tr>
<td>NN9535</td>
<td>Novo Nordisk</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>Taspoglutide/R1583/BIM-51077</td>
<td>Roche/Ipsen</td>
<td>Type 2 diabetes</td>
<td>3</td>
</tr>
<tr>
<td><strong>Biguanides</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metformin gum/buccal</td>
<td>Generex/Fertin Pharma</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td><strong>Thiazolidinediones/PPAR-γ Agonists</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balaglitazone/DRF-2593</td>
<td>Dr. Reddy’s Laboratories/Rheoscience</td>
<td>Type 2 diabetes</td>
<td>3</td>
</tr>
<tr>
<td>Mitoglitazone/MDSC 0160</td>
<td>Metabolic Solutions Development</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>Netoglitazone/MCC-555</td>
<td>Mitsubishi Tanabe/Perlegen</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>Rivoglitazone/CS-011</td>
<td>Daiichi-Sankyo</td>
<td>Type 2 diabetes</td>
<td>3</td>
</tr>
<tr>
<td><strong>Other PPAR Agonists</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aleglitazar/R1439</td>
<td>Roche</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>Indeglitzar</td>
<td>Pexxikon/Wyeth</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>INT 131/AMG131</td>
<td>Amgen/InteKrin Therapeutics</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>MBX 2044</td>
<td>Metabolex/Ortho-McNeil</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>Metaglidasen/MBX 102/JNJ-39659100</td>
<td>Metabolex/Ortho-McNeil</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>ONO-5129</td>
<td>Ono</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>PLX204/PPM-204</td>
<td>Pexxikon/Wyeth</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
</tbody>
</table>

*continued on p. 94*
### Table 1. Drugs in Development 1–3

<table>
<thead>
<tr>
<th>Generic/Code Name</th>
<th>Manufacturer</th>
<th>Indication</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Selective Sodium Glucose Cotransporter Inhibitors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASP1941</td>
<td>Astellas</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>AVE2268</td>
<td>Sanofi-Aventis</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>BI 10773</td>
<td>Boehringer Ingelheim</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>Dapagliflozin/BMS512148</td>
<td>AstraZeneca/Bristol-Myers Squibb</td>
<td>Type 2 diabetes</td>
<td>3</td>
</tr>
<tr>
<td>KGT-1681</td>
<td>GSK/Kissei</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>Remogliflozin/189075</td>
<td>GSK/Kissei</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>TA-7284</td>
<td>Mitsubishi Tanabe/Ortho McNeil</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>YM543</td>
<td>Astellas</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td><strong>Glinides</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mitiglinide</td>
<td>Elixir Pharmaceuticals</td>
<td>Type 2 diabetes</td>
<td>3</td>
</tr>
<tr>
<td><strong>Insulins</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhaled Technosphere insulin</td>
<td>Mannkind</td>
<td>Type 1 and type 2 diabetes</td>
<td>3</td>
</tr>
<tr>
<td>Insulin intranasal</td>
<td>Bentley</td>
<td>Type 1 and type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>Insulin intranasal</td>
<td>MDRNA</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>Oral HDV insulin</td>
<td>Diasome</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>Oral insulin spray</td>
<td>Generex</td>
<td>Type 1 and type 2 diabetes</td>
<td>3</td>
</tr>
<tr>
<td>NN1250 insulin analog for injection</td>
<td>Novo Nordisk</td>
<td>Type 1 and type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>NN5401 insulin analog for injection</td>
<td>Novo Nordisk</td>
<td>Type 1 and type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>Rapid-acting insulin for injection</td>
<td>Biodel</td>
<td>Type 1 and type 2 diabetes</td>
<td>3</td>
</tr>
<tr>
<td>Recombinant human hyaluroindase (rHuPH20)/insulin co-formulation for injection</td>
<td>Halozyme Therapeutics</td>
<td>Type 1 diabetes</td>
<td>2</td>
</tr>
</tbody>
</table>

* NDA, new drug application.

*continued on p. 95*
Sitagliptin and the other DPP-4 inhibitors in development are orally administered. Most have long half-lives enabling once-daily administration.6,7 Alogliptin

Alogliptin is a highly selective inhibitor of DPP-4, demonstrating > 10,000 times more selectivity for DPP-4 than for other related proteases. After oral administration of alogliptin in a range of doses from 2.5 to 800 mg, mean DPP-4 inhibition ranged from 93 to 99%, with mean inhibition at 24 hours after dosing ranging from 74 to 97%.8

Very little information has been published on the clinical efficacy and safety of alogliptin, although several large studies have been presented as abstracts at scientific meetings. Alogliptin is capable of decreasing the average A1C level in patients with type 2 diabetes when used alone or in combination with insulin, metformin, a sulfonylurea, or a thiazolidinedione.9-13 The information on common adverse reactions reported in the clinical trials with alogliptin is very limited but has included reports of hypoglycemia with an incidence similar to that of placebo.9-13 Adverse reactions reported have also included nasopharyngitis, headache, and upper respiratory tract infection.9 Alogliptin appears to have a neutral effect on weight and lipids.9-13

Table 2. Other Drugs in Development for Diabetes1-3 continued from p. 94

<table>
<thead>
<tr>
<th>Generic/Code Name</th>
<th>Manufacturer</th>
<th>Mechanism</th>
<th>Indication</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIO-902/2S, 4R ketoconazole</td>
<td>DiObex</td>
<td>Cortisol synthesis inhibitor</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>DM-71/bethanechol and N-acetyl cysteine</td>
<td>Diamedica</td>
<td>Unknown</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>DM-83/combo. of two generic compounds</td>
<td>Diamedica</td>
<td>Unknown</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>E1 INT</td>
<td>Transition Therapeutics</td>
<td>Islet regeneration factor</td>
<td>Type 1 and 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>Eprodisate/NC-503</td>
<td>Bellus Health</td>
<td>Serum amyloid A protein inhibitor</td>
<td>?</td>
<td>2</td>
</tr>
<tr>
<td>Ex vivo cultured adult human mesenchymal stem cells</td>
<td>Osiris</td>
<td>Mesenchymal stem cell therapy</td>
<td>Type 1 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>HE3286</td>
<td>Hollis-Eden</td>
<td>Insulin sensitizing (NF-kappaB/TLR4 pathway)</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>INCB 13739</td>
<td>Incyte</td>
<td>11-beta hydroxysteroid dehydrogenase inhibitor</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>INCB 19602</td>
<td>Incyte</td>
<td>GPR109A receptor agonist / HM74a agonist</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>INGAP peptide</td>
<td>Kinexum</td>
<td>Islet neogenesis associated protein</td>
<td>Type 1 and 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>ISIS 113715</td>
<td>Isis</td>
<td>PTP1B</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>MB 07803</td>
<td>Metabasis/Daiichi Sankyo</td>
<td>Fructose-1,6-bisphosphatase inhibitor</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>MK 0893</td>
<td>Merck</td>
<td>Unknown</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>MK 0941</td>
<td>Merck</td>
<td>Unknown</td>
<td>Type 2 diabetes</td>
<td>2</td>
</tr>
<tr>
<td>Otelixizumab/TRX4</td>
<td>GSK, Tolerx</td>
<td>Anti-CD3 MAb</td>
<td>Type 1 diabetes</td>
<td>3</td>
</tr>
<tr>
<td>rhGAD65/recombinant human glutamic acid decarboxylase</td>
<td>Diamyd Therapeutics</td>
<td>Vaccine/induces immunomodulation</td>
<td>Type 1 diabetes</td>
<td>3</td>
</tr>
<tr>
<td>Succinobucol/AGI 1067</td>
<td>AtheroGenics</td>
<td>Antioxidant/vascular cell adhesion molecule-1</td>
<td>Type 2 diabetes</td>
<td>3</td>
</tr>
<tr>
<td>Tagatose</td>
<td>Spherix</td>
<td>Attenuates intestinal glucose absorption</td>
<td>Type 2 diabetes</td>
<td>3</td>
</tr>
<tr>
<td>Teplizumab/MGA031/hOKT3gamma1(Ala-Ala)</td>
<td>Lilly/MacroGenics</td>
<td>Anti-CD3 MAb</td>
<td>Type 1 diabetes</td>
<td>3</td>
</tr>
<tr>
<td>TT-223</td>
<td>Lilly/Transition Therapeutics</td>
<td>Gastrin analog</td>
<td>Type 1 and 2 diabetes</td>
<td>2</td>
</tr>
</tbody>
</table>
With the addition of alogliptin to glyburide therapy in a randomized, double-blind, placebo-controlled study enrolling 500 patients with type 2 diabetes that was adequately controlled on glyburide alone, A1C was reduced to a greater extent with alogliptin 12.5 mg (–0.38%) and alogliptin 25 mg (–0.52%) than with placebo (+0.01%; P < 0.001). A reduction of ≥1% in A1C was achieved in 28.6% of patients treated with alogliptin 12.5 mg and 30% of those treated with alogliptin 25 mg, compared to 8.7% of those treated with placebo (P < 0.001).10 With the addition of alogliptin to insulin therapy in a randomized, double-blind, placebo-controlled study enrolling 390 patients with type 2 diabetes not adequately controlled on insulin alone or insulin plus metformin, A1C was reduced to a greater extent with alogliptin 12.5 mg (–0.63%) and alogliptin 25 mg (–0.71%) than with placebo (–0.13%; P < 0.001).11 Similar improvements in A1C were also observed with the addition of alogliptin to pioglitazone in patients with type 2 diabetes inadequately controlled on a thiazolidinedione alone or on a thiazolidinedione with metformin or a sulfonylurea, and with the addition of alogliptin to metformin therapy.12,13

**Dutogliptin**
Dutogliptin is also an oral DPP-4 inhibitor under evaluation for once-daily dosing in patients with type 2 diabetes. To date, it has demonstrated activity in a short-term study when administered once daily in conjunction with metformin or metformin plus a thiazolidinedione; participants are now being recruited for a phase 3 study.14,15

**Linagliptin**
Linagliptin is another oral DPP-4 inhibitor under evaluation for once daily dosing in patients with type 2 diabetes. To date, it has demonstrated activity in a short-term study when administered once daily in patients with type 2 diabetes; recruitment is ongoing for a number of phase 3 studies assessing linagliptin as monotherapy and in combination with pioglitazone, metformin, or metformin plus a sulfonylurea.16–21

**Saxagliptin**
Very little information has been published on the clinical efficacy and safety of saxagliptin. Saxagliptin is capable of decreasing the average A1C level in patients with type 2 diabetes when used alone or in combination with metformin, a sulfonylurea, or a thiazolidinedione.24–27 Treatment with saxagliptin alone has been weight neutral.25 Common adverse reactions reported in the clinical trials with saxagliptin include nasopharyngitis, headache, diarrhea, upper respiratory infections, influenza, and urinary tract infection.25,27

When administered as initial therapy in patients with type 2 diabetes in a randomized, double-blind 24-week study enrolling 1,306 patients, A1C was reduced 1.69% with saxagliptin alone, 1.99% with metformin alone, and 2.49–2.53% with saxagliptin plus metformin (P < 0.0001 for combination vs. either monotherapy). A1C < 7% was achieved in 60% of patients treated with the combination compared to 32% of those treated with saxagliptin alone and 41% of those treated with metformin alone.24 A1C reductions of 0.7–0.9% were observed in another study assessing saxagliptin monotherapy in drug-naïve patients with type 2 diabetes.25 When added to a sulfonylurea in a double-blind study enrolling 768 patients with type 2 diabetes, A1C reductions were in the range of 0.54–0.64%.25 When added to a thiazolidinedione in a double-blind study enrolling 565 patients with type 2 diabetes, A1C reductions were in the range of 0.66–0.94%, compared to 0.3% reductions with the addition of a placebo.26

Additional ongoing studies are assessing saxagliptin as initial monotherapy in patients with type 2 diabetes, as an addition to metformin, insulin, or insulin plus metformin, in comparison with sitagliptin when added to metformin, and in patients with renal impairment.28–33

**Vildagliptin**
Vildagliptin alone or in combination with metformin, a thiazolidinedione, or insulin is capable of decreasing fasting plasma glucose levels and improving A1C levels in patients with type 2 diabetes.

The efficacy of vildagliptin in drug-naïve patients with type 2 diabetes and “mild” hyperglycemia was evaluated in a multicenter, double-blind, randomized, placebo-controlled, parallel-group study that enrolled 306 patients. The baseline A1C for this population ranged from 6.2 to 7.5% and averaged 6.7% in the vildagliptin group and 6.8% in the placebo group. Patients were randomized to treatment with vildagliptin 50 mg or placebo once daily for 52 weeks. The change in the A1C level was −0.2% in the vildagliptin group and 0.1% in the placebo group; the between-group difference was 0.3% (P < 0.001). Fasting plasma glucose levels and postprandial plasma glucose levels all improved with vildagliptin compared to placebo. The patients’ mean body weight decreased by 0.5 kg with vildagliptin therapy and increased by 0.2 kg with placebo. Both drug therapies were well tolerated. With continued administration for an additional year in 131 patients, the placebo-adjusted change from baseline in A1C was −0.5% (P = 0.008).34,35 Additional monotherapy studies in drug-naïve patients with type 2 diabetes and baseline A1C levels of 8.3–8.7% demonstrated mean placebo-adjusted A1C reductions of 0.7–1.2% after therapy for 24 weeks at doses of 50 mg twice daily or 100 mg once daily.36,37

Several additional studies have assessed vildagliptin as monotherapy in comparison with other oral antidiabetic agents, including acarbose, metformin, pioglitazone, and rosiglitazone. The efficacy of vildagliptin was compared to acarbose in drug-naïve patients with type 2 diabetes in a multicenter, randomized, double-blind, parallel-arm study. Patients were given either vildagliptin 50 mg twice daily (n = 441) or acarbose (n = 220) in three equally divided doses (up to 300 mg daily) for 24 weeks. The average baseline A1C level in both groups was 8.6%. At the end of 24 weeks, the adjusted mean change from baseline was −1.4% in the vildagliptin group and −1.3% in the acarbose group. The decrease in plasma glucose was −1.2 mmol/l with vildagliptin and −1.5 mmol/l with acarbose. The body weight of the vildagliptin group remained unchanged (±0.4 ± 0.1 kg) and decreased by 1.7 ± 0.2 kg in the acarbose group.38

Vildagliptin has been compared to metformin as monotherapy in a 1-year study enrolling 780 drug-naïve patients with type 2 diabetes. Patients received vildagliptin 50 mg twice daily or metformin titrated to 1,000 mg twice daily. From a mean baseline A1C of 8.7%, A1C at 1 year declined by 1% with vildagliptin therapy and...
were treated with either vildagliptin or placebo in another multicenter, randomized, double-blind, placebo-controlled study. All 515 type 2 diabetic patients enrolled in this trial received glimepiride 4 mg once daily plus their assigned study medication for 24 weeks. The vildagliptin was given either as 50 mg once daily or 50 mg twice daily. Both vildagliptin doses were better than placebo in improving the patients’ A1C levels. The between-group difference (vildagliptin vs. placebo) for the A1C was ~0.6% with vildagliptin 50 mg once daily and ~0.7% with vildagliptin 50 mg twice daily (P < 0.001 vs. placebo).45

Similar improvements in A1C of ~0.5–1% were observed with the addition of vildagliptin to therapy with pioglitazone and the addition of vildagliptin to insulin.46,47

Adverse reactions reported in the clinical trials have generally been similar to those reported with placebo and have included cough, nasopharyngitis, headache, hypoglycemia, dizziness, dyspepsia, nausea, constipation, and diarrhea. Vildagliptin had no impact on patient weight in the majority of studies.

A study of the safety of vildagliptin in patients with type 2 diabetes and severe renal insufficiency, as required by the FDA, is currently underway.48

GLUCAGON-LIKE PEPTIDE 1 (GLP-1) ANALOGS

The GLP-1 analogs induce their activity through a glucose-dependent stimulation of insulin secretion, inhibition of glucagon secretion, slowing of gastric emptying, and reduction in appetite. The first marketed GLP-1 analog was exenatide, which was approved by the FDA in 2005. Exenatide is currently used as adjunctive therapy in type 2 diabetes in patients currently using metformin, a sulfonylurea, or pioglitazone in patients with type 2 diabetes, as well as a study comparing AVE0010 and exenatide in association with metformin in patients with type 2 diabetes.51–57

Exenatide LAR

The slow-release or long-acting release (LAR) formulation of exenatide is in phase 3 development. It is intended for once-weekly subcutaneous administration for the treatment of type 2 diabetes.

In a randomized, placebo-controlled study enrolling 45 patients with type 2 diabetes suboptimally controlled on metformin or diet and exercise, exenatide LAR administered subcutaneously once weekly for 15 weeks reduced A1C 1.4% (0.8 mg dose) and 1.7% (2 mg dose; both P < 0.0001). An A1C of ≤7% was achieved in 86% of subjects receiving the 3-mg dose. Patients in this dose group also experienced a 3.8-kg weight loss in this 15-week study (P < 0.05).58

In a non-inferiority study comparing exenatide LAR 2 mg once weekly with exenatide 10 mg twice daily in 295 patients with type 2 diabetes, patients treated with exenatide LAR had a greater reduction in A1C at 30 weeks than those treated with exenatide twice daily (−1.9% vs. −1.5%; 95% CI −0.54 to −0.12;...
P = 0.0023), A1C of ≤7% was achieved in 77% of patients treated with exenatide LAR compared to 61% of those treated with exenatide twice daily (P = 0.0039). Weight loss was similar in the two groups. Nausea and injection site pruritus were the most common adverse effects. After 30 weeks, 238 patients entered an open-label treatment with exenatide LAR. Improvements in A1C were sustained in patients continuing therapy with exenatide once weekly for 52 weeks (–2% from baseline) and were similar in those switched to once-weekly therapy (–2% from baseline). Patients in both groups lost ~4 kg of weight by week 52, and blood pressure and lipid profiles were improved in both groups.

**Liraglutide**

Liraglutide is under evaluation for use in the treatment of patients with type 2 diabetes as an adjunct to diet and exercise, either as monotherapy or in combination with commonly used diabetes medications, including sulfonylureas and metformin. In clinical trials, liraglutide has been associated with a reduction in A1C and fasting plasma glucose with either weight loss or no change in body weight. Significant reductions in A1C have been observed at doses of 0.1–2 mg administered subcutaneously once daily.

A randomized, double-dummy study has compared the addition of liraglutide to glimepiride therapy with glimepiride monotherapy or the addition of rosiglitazone to glimepiride in 1,041 patients with type 2 diabetes and baseline A1C of 8.4%. Patients received liraglutide 0.6, 1.2, or 1.8 mg once daily added to metformin 1 g twice daily, placebo plus metformin, or glimepiride 4 mg once daily added to metformin for 26 weeks. A1C was reduced 0.7% with liraglutide 0.6 mg and 1% with liraglutide 1.2 mg and 1.8 mg plus metformin, compared to an increase of 0.1% with metformin monotherapy and a reduction of 1% with glimepiride plus metformin. A1C < 6.5% was achieved in 11.3% of patients treated with liraglutide 0.6 mg plus metformin, 19.8% of those treated with liraglutide 1.2 mg plus metformin, 24.6% of those treated with liraglutide 1.8 mg plus metformin, compared to 4.2% of those treated with placebo plus metformin and 22.2% of those treated with glimepiride plus metformin.

Weight loss was greater in all three liraglutide plus metformin groups than in the glimepiride plus metformin group.

In another 26-week study enrolling 533 patients, liraglutide was added to metformin and rosiglitazone. A1C was reduced 1.48% in the groups treated with liraglutide 1.2 mg once daily and liraglutide 1.8 mg once daily in conjunction with metformin and rosiglitazone, compared to reductions of 0.54% in patients receiving placebo with metformin and rosiglitazone (P < 0.05 for both liraglutide doses vs. placebo). A1C < 7% was achieved in 58% of patients treated with liraglutide 1.2 mg and 54% of those treated with liraglutide 1.8 mg, compared to 28% of those treated with placebo (P < 0.05 for both liraglutide doses vs. placebo). Weight loss was also greater in the liraglutide groups (~1.02 and ~2.02 kg vs. +0.6 kg).

Liraglutide has also been compared to insulin glargine as add-on to therapy with metformin and glimepiride in a study enrolling 581 patients with type 2 diabetes and a baseline A1C of 8.2%. Patients received liraglutide 1.8 mg once daily, placebo, or insulin glargine in addition to metformin 1 g twice daily and glimepiride 2–4 mg once daily for 26 weeks. A1C was reduced 1.33% with the addition of liraglutide, 0.24% with the addition of placebo, and 1.09% with the addition of insulin glargine (P < 0.05 for liraglutide vs. placebo and insulin glargine). A1C < 6.5% was achieved in 37.1% of those treated with liraglutide compared to 10.9% of those in the placebo group and 23.6% of those in the insulin glargine group. A weight loss of 1.81 kg was observed in the liraglutide group compared to a loss of 0.42 kg in the placebo group and a weight gain of 1.62 kg in the insulin glargine group.

Adverse effects associated with liraglutide therapy have included headache, dizziness, nausea, and vomiting.

**LY2189265**

Results of studies with LY2189265 have not been published. Recruitment is currently ongoing for a phase 2/3 study comparing LY2189265 with sitagliptin in patients with type 2 diabetes on metformin.

**Taspoglutide**

Taspoglutide administered subcutaneously once weekly has been associated with reductions in fasting blood glucose, improvement in A1C, and weight loss when added to metformin therapy in patients with type 2 diabetes in short-term studies. Recruitment is ongoing for studies assessing taspoglutide as initial monotherapy and in conjunction with metformin, metformin plus pioglitazone, metformin plus a sulfonylurea, or metformin plus a thiazolidinedione. In several of these studies, taspoglutide is being compared head-to-head with exenatide, insulin glargine, and sitagliptin.

**PEROXISOME PROLIFERATOR–ACTIVATED RECEPTOR (PPAR) AGONISTS**

The PPAR-γ agonists act as insulin sensitizers, reducing fasting glucose and A1C. The thiazolidinediones were the first class of PPAR-γ agonists to be approved for use in diabetes. Balaglitazone and rivoglitazone are thiazolidinediones in phase 3 studies in patients with type 2 diabetes. Balaglitazone is a partial agonist; rivoglitazone is a full agonist. The
partial PPAR-γ agonists, also known as selective PPAR modulators, have been developed in an attempt to minimize the side effects of the full agonists while maintaining the therapeutic effect. Insufficient data are available at this time to determine if the selective PPAR modulators will have fewer adverse effects. In light of the recent experience with rosiglitazone, long-term studies will likely be required for approval of any new drugs in this class.

Other PPAR agonists in early-phase development include the dual agonists or glitazars, which stimulate both PPAR-α and -γ receptors, resulting in effects on insulin resistance and dyslipidemia, and pan agonists, which act at the α-, γ-, and δ PPAR receptors and may have activity in diabetes, dyslipidemia, and obesity.

Balaglitazone
Balaglitazone is a selective partial PPAR-γ agonist. It has been suggested that partial PPAR-γ agonists may have a favorable adverse effect profile relative to the full PPAR-γ agonists pioglitazone and rosiglitazone. However, results of clinical studies directly comparing these agents are not yet available. A phase 3 study assessing the efficacy and safety of balaglitazone compared to pioglitazone in patients with type 2 diabetes receiving stable insulin therapy is currently enrolling patients.

Rivoglitazone
Rivoglitazone is a potent PPAR-γ agonist currently under evaluation in a phase 3 study comparing it to placebo and pioglitazone in patients with type 2 diabetes not adequately controlled with diet and exercise or with nonthiazolidinedione antihyperglycemic monotherapy. In an earlier open-label comparative 6-week study, rivoglitazone 2-mg and 5-mg doses once daily were associated with greater reductions in fasting plasma glucose than pioglitazone 30 mg; however, these rivoglitazone doses were also associated with a greater incidence of peripheral edema and weight gain. In a double-blind 26-week study comparing rivoglitazone and pioglitazone in patients with type 2 diabetes, rivoglitazone doses of 2 mg and 3 mg were associated with greater reductions in A1C than pioglitazone 45 mg; however, rivoglitazone was again associated with higher incidence of peripheral edema and weight gain.

The ongoing study is comparing rivoglitazone 1-mg and 1.5-mg doses with pioglitazone 45 mg.

SELECTIVE SODIUM GLUCOSE COTRANSPORTER 2 INHIBITORS
The selective sodium glucose cotransporter 2 inhibitors are a new class of agents. The sodium glucose cotransporter type 2 (SGLT2) located in the plasma membrane of cells lining the proximal tubule mediates the majority of renal glucose reabsorption from the tubular fluid. Blood glucose is continuously filtered by the renal glomeruli and then reabsorbed in the renal proximal tubules by SGLT2, and to a lesser extent SGLT1, preventing the loss of glucose in the urine. Competitive inhibitors of SGLT2 provoke renal excretion of glucose, potentially lowering elevated blood glucose levels in patients with diabetes. These agents are expected to improve plasma glucose levels and decrease body weight in patients with type 2 diabetes without causing hypoglycemia.

Dapagliflozin is the only agent in this class in phase 3 studies.

Dapagliflozin
Dapagliflozin is in the early portion of phase 3 development for use as a monotherapy agent or in combination with other oral hypoglycemic agents. The drug has been well tolerated in early clinical studies with the most common adverse reactions being urinary tract infection, dizziness, headache, fatigue, back pain, and nasopharyngitis.

In a randomized, double-blind, placebo-controlled, dose-ranging 12-week study enrolling 389 treatment-naïve patients with type 2 diabetes, dapagliflozin doses from 2.5 to 50 mg once daily were associated with greater reductions in A1C than placebo (−0.55% to −0.9% vs. −0.18%; P < 0.01). Fasting plasma glucose was reduced at doses from 5 to 50 mg once daily compared with placebo (−19.3 to −30.5 vs. −5.8 mg/dL; P < 0.01). Urinary glucose excretion ranged from 51.8 to 85 g/day at week 12 in the dapagliflozin arms compared with 5.8–10.9 g/day at baseline and 5.7 g/day at 12 weeks in the placebo group. Mean weight loss at week 12 ranged from 2.5 to 3.2% in the dapagliflozin groups compared with 1.2% in the placebo group.

Dapagliflozin is currently under evaluation in a number of phase 3 studies assessing the agent as monotherapy in patients with type 2 diabetes not adequately controlled with diet and exercise, as well as studies assessing dapagliflozin in conjunction with metformin, a sulfonylurea, a thiazolidinedione, or insulin.

GLINIDES
The glinides, including nateglinide, repaglinide, and mitiglinide, are agents that enhance mealtime insulin secretion and reduce postprandial hyperglycemia. Nateglinide and repaglinide have been available in the United States since 2000 and 1997, respectively.

Mitiglinide
Mitiglinide has been available in Japan since 2004 and is currently in phase 3 studies in the United States. It has been reported to have a more β-cell-selective effect on the adenosine triphosphate-dependent potassium channels than nateglinide and repaglinide and to have no active metabolites or cytochrome P450 drug interactions.

Several recently published studies conducted in Japan have assessed premeal mitiglinide combined with once-daily insulin glargine and twice-daily premixed insulin. In a study comparing mitiglinide with acarbose in elderly patients, glycemic control was better maintained in the mitiglinide group at 6 months (A1C 7.43% in the mitiglinide group and 7.75% in the acarbose group; P < 0.001). In a study assessing mitiglinide in combination with metformin compared with metformin alone or mitiglinide alone, glycemic control was better in the group receiving the combination at 7 months (A1C 7.13% vs. 7.7% on metformin alone, P < 0.001). An additional ongoing study is assessing mitiglinide in combination with metformin compared to metformin alone.

INSULINS
A variety of insulin formulations are currently in development including inhaled formulations, intranasal formulations, oral formulations, and injectable analogs.

Inhaled Technosphere Insulin
Inhaled Technosphere insulin is an inhaled insulin in development for administration using a palm-sized device.
handheld breath-activated inhaler. The Technosphere particles are composed of human regular insulin loaded into a diketopiperazine molecule. The particles dissolve rapidly at physiological pH, providing for rapid insulin absorption from the lungs.\textsuperscript{98} Technosphere insulin is absorbed within 15 minutes, has an onset of action of ~ 25–30 minutes, and has a duration of action of ~ 2–3 hours.\textsuperscript{98}

In a study comparing inhaled Technosphere insulin and insulin lispro as prandial insulin in conjunction with basal insulin glargine in a 12-week study enrolling 111 patients with type 1 diabetes, inhaled insulin was associated with fewer postprandial glucose excursions, less late postprandial hypoglycemia, and greater weight loss. A1C was improved in both groups but did not differ between groups.\textsuperscript{99} In a 12-week study assessing inhaled Technosphere insulin in 126 patients with type 2 diabetes not adequately controlled with oral agents, inhaled insulin reduced the mean A1C by 0.72\% compared to a reduction of 0.3\% in the placebo group (\(P = 0.003\)). Postprandial glucose excursions were reduced 56\%. Body weight was unchanged.\textsuperscript{98} In other smaller studies, inhaled Technosphere insulin was associated with improvements in postprandial glycemic control in patients with type 2 diabetes and glycemic control without weight gain in both type 1 and type 2 diabetes.\textsuperscript{100,101}

Other studies are assessing inhaled Technosphere insulin compared to insulin aspart in type 1 diabetes, with basal insulin glargine compared to a regimen of insulin lispro and insulin glargine in type 1 diabetes, with basal insulin compared to subcutaneous premixed insulin therapy in type 2 diabetes, and in combination with metformin or compared to oral antidiabetic agents in patients with type 2 diabetes.\textsuperscript{102–105}

Inhaled Technosphere insulin did not affect pulmonary function in a 6-month study enrolling 306 patients with type 2 diabetes.\textsuperscript{106} An additional 2-year study is currently assessing pulmonary outcomes in patients with type 1 or type 2 diabetes treated with Technosphere insulin.\textsuperscript{107}

**Oral Insulin Spray**

An oral insulin spray in development by Generex Biotechnology is in phase 3 studies in the United States but has already been approved in Ecuador and India. The insulin is absorbed buccally following administration with a proprietary RapidMist device that resembles the metered-dose inhalers used in the treatment of asthma. The formulation is tasteless and odorless.\textsuperscript{108}

Compared to preprandial subcutaneous injection of regular insulin, preprandial oral insulin spray was associated with similar pre- and postmeal glucose concentrations.\textsuperscript{109} Compared to a regimen of premeal subcutaneous regular insulin and twice-daily NPH insulin, a regimen of mealtime (half-dose before meal and half-dose after meal) oral insulin spray plus twice-daily NPH insulin was associated with greater reduction in A1C.\textsuperscript{110} Compared to a regimen of once-daily subcutaneous insulin glargine and premeal insulin lispro, a regimen of twice-daily NPH insulin plus mealtime oral insulin spray was also associated with lower premeal glucose, A1C, and fructose during a 372-day treatment period.\textsuperscript{111} Additional small preliminary studies have assessed mealtime oral insulin spray in adolescents with type 1 diabetes, in adults with type 2 diabetes requiring insulin injections, in conjunction with metformin in patients with type 2 diabetes not adequately controlled with oral agents, and as initial therapy in patients with type 2 diabetes not adequately controlled with diet and exercise.\textsuperscript{108,112}

A 26-week phase 3 study is currently underway comparing oral insulin spray to subcutaneous regular human insulin in patients with type 1 diabetes receiving twice-daily NPH insulin. The oral insulin is administered as half the dose immediately before meals and half the dose immediately after meals. Subcutaneous regular human insulin is administered 30 minutes before meals. All patients receive twice-daily NPH insulin.\textsuperscript{113}

**Rapid-Acting Insulin for Injection (VIAject)**

VIAject is a novel ultra-fast insulin formulation composed of human soluble insulin and ingredients designed to increase the rate of absorption (EDTA and citric acid). These ingredients pull the zinc ions away from human insulin hexamers and mask charges on the surface of the insulin molecule, causing the insulin hexamers to dissociate and preventing re-association to the hexameric state with subcutaneous administration.\textsuperscript{114} VIAject has exhibited a quicker onset of action than insulin lispro and human soluble insulin (time to early half-maximal activity 33 minutes with VIAject vs. 51 minutes with insulin lispro and 66 minutes with human soluble insulin; \(P < 0.05\)).\textsuperscript{115} When administered immediately before a meal, VIAject was associated with improved postprandial blood glucose control, reduced hyperglycemia in the first 3 hours after a meal, and reduced hypoglycemia through 8 hours compared to regular human insulin.\textsuperscript{115}

Phase 3 studies comparing insulin VIAject and regular human insulin in patients with type 1 and type 2 diabetes have recently been completed.\textsuperscript{116,117}

**Other AGENTS**

A wide variety of other agents are also in development for the treatment of type 1 or type 2 diabetes.

**Bromocriptine**

Bromocriptine is a dopamine D2 receptor agonist that is approved for the treatment of dysfunctions associated with hyperprolactinemia, acromegaly, and Parkinson's disease and has been in development for the treatment of type 2 diabetes for several years. A new drug application for a quick-release formulation was granted approvable status by the FDA in 2006. However, at least one additional safety study was necessary before the drug could be approved.\textsuperscript{118}

Results of the studies submitted in support of approval have not been published. In one small study in patients with type 2 diabetes, bromocriptine was associated with reduced fasting plasma glucose and reduced A1C.\textsuperscript{119} The required 1-year randomized, double-blind, placebo-controlled safety study enrolled 3,070 patients with type 2 diabetes. A1C was reduced 0.6\% more in the bromocriptine-treated subjects than in the placebo-treated subjects compared to baseline. Target A1C of \(\leq 7\%\) was achieved in 32\% of the bromocriptine group compared to 10\% of the placebo group (\(P = 0.0001\)). Reductions were consistently greater in the bromocriptine group than in the placebo group when combined with multiple oral hypoglycemic agents, including metformin, sulfonylureas, thiazolidinediones, and combinations of these oral hypoglycemic agents.\textsuperscript{120}
Otelixizumab

Otelixizumab is a humanized anti-CD3 monoclonal antibody currently being evaluated in clinical studies in patients with new-onset type 1 diabetes. Otelixizumab binds to the CD3/TCR complex and blocks full T-cell activation, proliferation, and cytokine release. It has been hypothesized that otelixizumab’s downregulation of T effector cells via binding of the T-cell receptors will result in inhibition of the autoimmune attack on β-cells in the pancreatic islets and establishment of long-lasting operational tolerance by the generation and expansion of regulatory T-cells, which prevent further autoimmune destruction.121

A phase 3 study is currently underway assessing whether an 8-day series of otelixizumab infusions will lead to greater improvement in insulin secretion than placebo in adults 18–35 years of age with new-onset type 1 diabetes.122

Recombinant Human Glutamic Acid Decarboxylase-65 (rhGAD65)

RhGAD65 is a vaccine that induces immunotolerization and may thereby slow or prevent autoimmune destruction of pancreatic islet cells.123 Antibodies against GAD are present at the time of diagnosis in 80–90% of patients with type 1 diabetes.124 In patients with adult-onset autoimmune diabetes and the presence of antibodies against GAD, administration of rhGAD65 has been associated with reduced AIC and increased fasting and stimulated C-peptide levels for 2 years.124,125

Two phase 3 studies were recently initiated to assess whether rhGAD65 formulated in alum preserves the body’s own insulin-producing capacity in patients recently diagnosed with type 1 diabetes. One study will enroll subjects 10–20 years of age; the other will enroll subjects 8–45 years of age. Results will not be available for several years.121,126

Succinobucol

Succinobucol is an oral antioxidant lipid peroxidation inhibitor and vascular cell adhesion molecule antagonist that is in phase 3 development for the treatment of atherosclerosis and type 2 diabetes. It is a monosuccinate ester of probucol, a previously approved lipid-lowering agent.127

The first of these studies failed to achieve its primary endpoint in the treatment of patients with acute coronary syndrome. The double-blind, placebo-controlled multicenter trial was designed to evaluate the efficacy of succinobucol in the treatment of acute coronary syndrome in 6,144 patients. Patients were randomized to succinobucol 300 mg/day or placebo. The primary endpoint for the study was the composite of cardiovascular death, resuscitated cardiac arrest, myocardial infarction, stroke, unstable angina, or coronary revascularization. The secondary endpoints were primary composite endpoint with all-cause death, primary composite endpoint without coronary revascularization, and primary composite endpoint without coronary revascularization or unstable angina. After 24 months of treatment, the primary endpoint of the study was the same in both the succinobucol and placebo groups (17.2% vs. 17.3%, respectively; \( P = 0.99 \)). However, the secondary endpoint of cardiovascular death, cardiac arrest, myocardial infarction, or stroke was lower in patients randomized to succinobucol (6.7% vs. 8.2%, \( P = 0.028 \). New-onset atrial fibrillation occurred more frequently in the succinobucol group (hazard ratio [HR] 1.87, 95% CI 1.67–2.09; \( P = 0.0002 \)). New-onset diabetes occurred less frequently in the succinobucol group (HR 0.37, 95% CI 0.24–0.56; \( P < 0.0001 \)). This study included 2,271 patients with type 2 diabetes at study entry with a mean AIC of 7.2% who were followed for an average of 2 years. AIC was reduced in the succinobucol treatment group. An AIC of < 7% was achieved in 68.9% in the succinobucol group compared to 57.8% of the placebo group (\( P < 0.001 \)).128

The manufacturer has reported preliminary results from a recently completed phase 3 study enrolling 999 patients with type 2 diabetes treated with succinobucol or placebo. The primary endpoint for the study was the change in AIC at the end of 6 months of therapy. AIC was reduced 0.6% in the succinobucol 150 mg group (\( P < 0.001 \)) and 0.4% in the succinobucol 75 mg group (\( P = 0.016 \)) compared to baseline, whereas AIC was reduced 0.2% in the placebo group. Succinobucol was not associated with weight gain or hypoglycemia. Liver enzyme elevations were observed in a small number of succinobucol-treated patients.130,131

Tagatose

Tagatose is a naturally occurring, sweet-tasting, low-calorie monosaccharide hexoketose found in dairy products. It is the epimer of D-fructose. Tagatose was originally developed as a sugar substitute for calorie and weight control. It was granted “Generally Recognized as Safe” status for use as a sweetener in foods and beverages by the FDA in 2001.132

The product in development by Spherix for the treatment of diabetes is produced by isomerization of galactose, which is produced by the hydrolysis of lactose derived from whey.132 Oral administration of this product decreases the postprandial glucose peaks seen in patients with type 2 diabetes when it is administered before meals.133 Administration three times a day with meals in patients with type 2 diabetes has been associated with weight loss, reduced A1C, and increased HDL cholesterol levels.134 It is believed to exert its effect on postprandial glucose by attenuating glucose absorption in the intestine, as well as increasing glycogen synthesis and decreasing glycogen utilization.132,133 Adverse effects have primarily included diarrhea, nausea, and flatulence.133,134 The current 1-year clinical trial to demonstrate the efficacy of tagatose as monotherapy in the treatment of type 2 diabetes is scheduled for completion in 2009.132,135

Teplizumab

Teplizumab is a humanized anti-CD3 monoclonal antibody. Like otelixizumab, teplizumab is hypothesized to minimize cytokine release and prevent the progressive destruction of β-cells.136

Teplizumab was administered to 12 patients with new-onset type 1 diabetes in a placebo-controlled phase 1/2 study. Teplizumab was administered as a daily intravenous injection for 14 consecutive days within 6 weeks after diagnosis. After 1 year, insulin production was maintained or improved in 9 of the 12 patients treated with teplizumab compared to 2 of 12 placebo recipients (\( P = 0.01 \)). A1C levels and insulin doses were reduced and C-peptide responses were maintained in the teplizumab group compared to the placebo group at 1 year and 2 years after treatment. Adverse effects included fever, rash, and anemia.137,138
A phase 3 study is currently evaluating the effects of 14 days of intravenous teplizumab in patients 8–35 years of age with new-onset type 1 diabetes, followed by retreatment at 6 months. The primary study endpoint is a successful clinical response as assessed by subjects’ total daily insulin usage and A1C at 1 year.\textsuperscript{136,139}

**CONCLUSION**

A wide range of agents are in development for use in the treatment of type 1 or type 2 diabetes. All of these agents appear to be effective in improving glycemic control, but it is unknown whether they will have an impact on the course of the disease or alter the micro- and macrovascular consequences of uncontrolled diabetes. One of the DPP-4 inhibitors is most likely to reach market next, as well as possibly liagliptin or sitagliptin. The PPAR-γ agonists and SGLT2 inhibitors are still early in phase 3 development.

**References**

6. Thomas L, Eckhardt M, Langkopf E, Tadayon M, Himmelsbach P, Mark M: (R)-8-(3-amino-piperidin-1-yl)-7-butyryl-3-methyl-(1-(4-methylquinazolin-2-yl)methyl)-3,7-dihydro-purine-2,6-dione (BI 1356), a novel xanthine-based dipeptidyl peptidase 4 inhibitor, has a superior potency and longer duration of action compared with other dipeptidyl peptidase-4 inhibitors. *J Pharmacol Exp Ther* 325:175–182, 2008


a new rapid onset and short duration insulin secretagogue, to standard metformin for type 2 diabetes mellitus (T2DM) in a large randomized, double-blind trial [abstract]. Diabetes 56 (Suppl. 1):A553, 2007


Boss AH, Baughman RA, Evans SH, Firsov I, Kramer DA, Richardson P: A 3 month comparison in type 1 diabetes of inhaled Technosphere®/insulin (TI) to sc administered rapid-acting insulin analogue (RAA) as prandial insulin in a basal/prandial regimen [abstract]. Diabetes 55 (Suppl. 1):A97, 2006


Tu N, Kramer D, Baughman R: Inhaled Technosphere®/insulin improves glycemic control without weight gain [abstract]. Diabetes 56 (Suppl. 1):A125, 2007


Diabetes Spectrum Volume 22, Number 2, 2009

From Research to Practice/Pharmacological Management of Type 2 Diabetes

105


Terri L. Levien, PharmD, is a clinical associate professor of pharmacotherapy, and Daniel E. Baker, PharmD, FASHP, FASCSP, is a professor of pharmacology and director of the Drug Information Center in the College of Pharmacy at Washington State University in Spokane.