Diabetes mellitus, defined as a fasting plasma glucose of ≥126 mg/dL or a glycosylated hemoglobin A1c level (HbA1c) of ≥6.5%, affects ≈12.9% of adults in the United States and nearly 285 million adults worldwide. Diabetes mellitus is a major risk factor for the development of cardiovascular disease, independently conferring a 2-fold excess risk of coronary heart disease and stroke. Macrovascular events in diabetes mellitus remain the leading cause of mortality, and the burden of cardiovascular disease attributable to diabetes mellitus has increased over the past decade. An increase in the prevalence of obesity has contributed to the rise in diabetes mellitus. Additionally, obesity independently increases the risk of cardiovascular disease in patients with diabetes mellitus.

Although strict glycemic control unequivocally reduces the microvascular complications of diabetes mellitus, the macrovascular benefits of intensive therapy have been difficult to establish, with conflicting results from large clinical trials. Multifactorial strategies are recommended to reduce cardiovascular risk in diabetes mellitus through enhanced glycemic control, blood pressure reduction, lipid management, weight loss, and physical activity. Unfortunately, despite aggressive interventions for hyperglycemia, <50% of patients achieve standard HbA1c targets with conventional therapy. Polypharmacy is required to achieve glycemic control in the treatment of patients with type 2 diabetes mellitus, focusing on the clinical evidence for currently available therapies, adverse effects, and the implications of therapy for patients at high risk of cardiovascular disease.

**Pathophysiology of Diabetes Mellitus and the Role of Incretins**

Type 2 diabetes mellitus is associated with a complex array of metabolic derangements, principally characterized by a progressive hormonal failure of adequate insulin release from pancreatic β-cells. At first diagnosis of diabetes mellitus, β-cell function is typically 50% lower than baseline and progressively declines despite treatment. Other pathophysiological defects include inappropriate glucagon release, aberrant hepatic glucose output, insulin resistance, increased lipolysis, and apoptosis of pancreatic β-cells leading to a relative deficit in β-cell mass. Glucose toxicity and lipotoxicity from elevated circulating free fatty acids and triglycerides are believed to accelerate declines in β-cell function.

The blunted efficacy of incretins also plays a pivotal role in the pathogenesis of diabetes mellitus. Incretins are peptides secreted by gastrointestinal cells in response to the ingestion of oral nutrients to potentiate pancreatic β-cell insulin production in normal homeostasis. An “incretin effect” was first established in the 1960s when the administration of enteral glucose provoked a more robust release of endogenous insulin than an equivalent parenteral glucose load. Two molecules, glucose-dependent insulinotropic polypeptide and GLP-1, account for nearly 90% of the “incretin effect.” Glucose-dependent insulinotropic polypeptide is secreted by the K cells in the proximal small intestine and augments glucose-stimulated insulin release. It is rapidly degraded by DPP-IV, limiting the plasma half-life to 5 to 7 minutes. GLP-1 is a 30-amino-acid peptide secreted from the L cells of the distal small intestine in response to luminal stimulation. Circulating GLP-1 is also rapidly degraded by DPP-IV, yielding a plasma half-life of only 1 to 2 minutes. GLP-1 binds receptors expressed in the endocrine pancreas, stimulates glucose-dependent insulin secretion from the pancreatic β-cells, enhances insulin gene transcription and biosynthesis, and inhibits glucagon secretion. In animal models, GLP-1 can reduce cellular apoptosis in the pancreatic β-cells and promote β-cell proliferation and neogenesis.
from pancreatic progenitor cells.\textsuperscript{21} GLP-1 attenuates gastrointestinal secretions, mobility, and gastric emptying, and may have direct effects on the hypothalamus to decrease appetite, causing earlier satiety and promoting weight loss. Weight loss, in turn, reduces insulin resistance and can facilitate normoglycemia. Many of the normal metabolic effects of GLP-1 appear to be independent of the GLP-1 receptor, suggesting dual pathways of GLP-1 action or plasticity in the incretin axis.\textsuperscript{22}

In healthy individuals, incretin release is responsible for nearly 50\% to 70\% of insulin secreted in response to ingested carbohydrates. However, in patients with type 2 diabetes mellitus, the incretin axis appears to be markedly compromised. Early studies reported reduced postprandial GLP-1 secretion in diabetic patients that was associated with muted incretin-mediated glucose-dependent insulin secretion.\textsuperscript{23} More recent data have called this finding into question, demonstrating a variable response of GLP-1 secretion and suggesting that GLP-1 levels depend on other factors such as age and plasma glucagon level.\textsuperscript{24} GLP-1 resistance, not necessarily deficiency, may contribute to the deterioration of the incretin effect in diabetes mellitus.\textsuperscript{25}

The Incretin Axis as a Drug Target

Two classes of incretin-based therapy have been developed to treat diabetes mellitus. Synthetic GLP-1 receptor agonists resistant to DPP-IV are attractive incretin mimetics because of their hypoglycemic effects, delayed gastric emptying and a propensity for weight loss, and potential cardiovascular benefits. Oral DPP-IV inhibitors delay enzymatic degradation of endogenous incretin peptides and offer more modest improvements in insulin secretion and decreased glucagon production. Exogenous glucose-dependent insulinolectopic polypeptide has not been regarded as an attractive drug therapy based on the peptide’s blunted downstream insulinotropic effects in the setting of diabetes mellitus.

The first incretin mimetic, exenatide, is a 39-amino-acid synthetic GLP-1 receptor analogue resistant to DPP-IV degradation. It is a based on the exendin-4 peptide identified in the salivary secretions of the Heloderma suspectum (ie, Gila monster) in 1992. The US Food and Drug Administration (FDA) approved exenatide in April 2005 as a twice-daily injectable adjunctive treatment for the management of diabetes mellitus. A once-weekly injectable formulation of exenatide with an extended half-life of 2 weeks was also developed. Both formulations undergo renal clearance and are associated with nausea, vomiting, and headaches in patients with severe renal impairment.\textsuperscript{26}

Liraglutide, a human GLP-1 analogue with a 1-amino-acid substitution (Arg34Lys) and palmitic acid side chain with a glutamyl spacer also achieved resistance to DPP-IV degradation, and has a long half-life of 13 hours. In contrast to exenatide, liraglutide is not renally cleared and appears safe in patients with renal insufficiency.\textsuperscript{27} The FDA approved liraglutide in 2010 as a once-daily injectable therapy for glycemic control in type 2 diabetes mellitus. Several new GLP-1 agonists remain in development, including albigrlutide and lixisenatide.

Clinical Outcomes of GLP-1 Receptor Agonist Therapy

Glycemic end points have long been sufficient to demonstrate efficacy and ensure regulatory approval of new therapies in diabetes mellitus. In 2008, the FDA released guidance for industry requesting that novel antidiabetic therapies demonstrate acceptable cardiovascular safety in clinical outcomes trials.\textsuperscript{28} Reductions in macrovascular outcomes and cardiovascular mortality are now viewed as an important goal of new diabetic therapies in patients with cardiovascular disease.

GLP-1 agonists hold great promise to improve the management of diabetes mellitus and its complications (Table 1). GLP-1 therapies offer potent glycemic control with a glucose-dependent incretin effect that mitigates the risk of hypoglycemia. The highest maintenance doses of GLP-1 agonists yield mean HbA1c reductions of −1.1 to −1.6%.\textsuperscript{29} The GLP-1 agonist class achieves a mean weight loss of 2.0 to 2.4 kg relative to placebo and 4.8 kg of weight loss versus insulin in trials lasting 20 to 52 weeks.\textsuperscript{30} The subcutaneous route of administration and tolerability of the class remain concerns. GLP-1 analogues are associated with gastrointestinal side effects, in particular, an increase in nausea, vomiting, and diarrhea.\textsuperscript{30,31} Gastrointestinal symptoms are dose related and typically abate with time and gradual dose titration.

Early placebo-controlled trials of twice-daily exenatide as an adjunct to sulfonylureas, thiazolidinediones, metformin, or combination therapy reported nearly a 0.9% decrease in HbA1c with minimal hypoglycemia, dose-dependent weight loss, and only mild gastrointestinal side effects.\textsuperscript{32–35} Durable benefits of long-term exenatide therapy were observed in a ≥3-year open-label follow-up to the initial clinical trials, with sustained improvements in glycemic control, enhanced lipid profiles, and persistent weight loss.\textsuperscript{36} Despite these encouraging findings, analyses from extensions of the initial trials must be interpreted with caution, because patients able to

### Table 1. Prescribing GLP-1 Agonists

<table>
<thead>
<tr>
<th>Brand</th>
<th>Exenatide (Twice Daily)</th>
<th>Exenatide (Once Weekly)</th>
<th>Liraglutide</th>
<th>Lixisenatide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Byetta</td>
<td>Bydureon</td>
<td></td>
<td>Victoza</td>
<td>Lyxumia</td>
</tr>
<tr>
<td>Availability</td>
<td>USA, EU</td>
<td>USA, EU</td>
<td>USA, EU</td>
<td>EU</td>
</tr>
<tr>
<td>Initial dose</td>
<td>5 μg subQ</td>
<td>2 mg subQ</td>
<td>0.6 mg subQ</td>
<td>10 μg daily for 14 days, then increase to 20 μg daily</td>
</tr>
<tr>
<td>twice daily</td>
<td>(60 min before a meal)</td>
<td>once weekly</td>
<td>daily once weekly, then increase to 1.2 mg daily</td>
<td>20 μg daily</td>
</tr>
<tr>
<td>Renal adjustment</td>
<td>Caution with eGFR 30−50</td>
<td>Caution with eGFR 30−50</td>
<td>Caution with eGFR 30−50</td>
<td>Caution with eGFR 30−50</td>
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<tr>
<td>Avoid if eGFR &lt;30</td>
<td>Avoid if eGFR &lt;30</td>
<td>Avoid if eGFR &lt;30</td>
<td>Avoid if eGFR &lt;30</td>
<td>Avoid if eGFR &lt;30</td>
</tr>
<tr>
<td>Maximal dose</td>
<td>10 μg subQ</td>
<td>2 mg subQ</td>
<td>1.8 mg subQ</td>
<td>20 μg daily</td>
</tr>
<tr>
<td>twice daily</td>
<td>(60 min before a meal)</td>
<td>once weekly</td>
<td>once daily</td>
<td>20 μg daily</td>
</tr>
<tr>
<td>Half-life</td>
<td>2.4 h</td>
<td>2 wk</td>
<td>13 h</td>
<td>3 h</td>
</tr>
</tbody>
</table>

**Common ADRs**

Nausea, vomiting, diarrhea, constipation, local injection site reactions, hypoglycemia, headache

ADR indicates adverse drug reaction; eGFR, estimated glomerular filtration rate; EU, European Union; GLP-1, glucagon-like peptide-1; subQ, subcutaneous.
complete the trial reflect a selection bias that may deliver inappropriately optimistic results. Exenatide also demonstrated enhanced glycemic control in patients already receiving basal insulin with or without metformin and/or pioglitazone without an increased rate of hypoglycemia and with significant weight loss.42 These early studies established exenatide as an effective adjunctive therapy to reduce HbA1c in patients already on a broad range of conventional diabetic regimens.

The development of once-weekly exenatide delivered incremental improvements in glucose control in comparison with twice-daily therapy and provided 1.6% to 1.9% reductions in HbA1c that were sustained at 2 years.38,39 Weight loss, modest improvements in systolic blood pressure, serum lipid profiles, decreased triglycerides, total cholesterol, and low-density lipoprotein cholesterol were also observed.40,41 The GLP-1 agonist liraglutide also amassed provocative clinical outcomes data. Liraglutide provides superior HbA1c reductions (1.12%) with similar weight loss and less common side effects of nausea and minor hypoglycemia.42 In an open-label comparison of daily liraglutide and once-weekly exenatide in patients with poorly controlled diabetes mellitus on oral hypoglycemic agents, liraglutide demonstrated a larger reduction in HbA1c and a greater reduction in body weight. The study failed to meet the primary end point of exenatide noninferiority.43

GLP-1 agonists also compare favorably in comparison with conventional classes of diabetes mellitus therapy. Exenatide demonstrated HbA1c lowering (1.5%) that was superior to sitagliptin or pioglitazone (0.9% and 1.2%, respectively) and was also associated with significantly lower body weight and a comparable safety profile.44 Randomized comparisons of exenatide and liraglutide with sitagliptin confirmed superior HbA1c lowering with the GLP-1 agonist therapy with more frequent gastrointestinal side effects but similar rates of hypoglycemia.45,46 Liraglutide also demonstrated durable superiority to glimepiride monotherapy in early type 2 diabetes mellitus with greater reductions in A1C, blood pressure, and body weight, with fewer hypoglycemic episodes.47,48

The potency of GLP-1 agonists affords an opportunity to delay the initiation of insulin. In the Liraglutide Effect and Action in Diabetes 5 (LEAD-5) trial, patients with diabetes mellitus who were on metformin and sulfonylurea therapy were randomly assigned to liraglutide or insulin glargine. Liraglutide demonstrated improved reductions in HbA1c in comparison with insulin (1.33% versus 1.09%), meeting the study noninferiority end point.49 In addition, liraglutide was associated with weight loss in comparison with the weight gain observed in the cohort receiving basal insulin (treatment difference 3.43 kg). Blood pressure reductions were observed in the GLP-1 arm, but not in the cohort receiving insulin. There were no differences between liraglutide and insulin in the occurrence of hypoglycemic episodes, but liraglutide was associated with significantly more nausea and diarrhea. Once-weekly exenatide also demonstrated similar success in head-to-head trials with insulin.50 Although these trials suggest that GLP-1 agonists provide glycemic control superior to insulin, inadequate titration of insulin could limit the external validity of the study findings.40,50

### Beyond Glucose Control: The Promise for Cardiovascular Disease

GLP-1 agonist therapy holds promise in the management of diabetic patients with poorly controlled hyperglycemia and cardiovascular disease (Table 2).51 Multiple mechanisms of hyperglycemia’s detrimental effects on the cardiovascular system have been postulated, including the effects of advanced glycation end-products, impaired endothelial function, aberrant thrombosis and fibrinolysis, increased inflammation, atherogenic dyslipidemia, and increased plasma levels of free fatty acids. Beyond excellent glycemic control, GLP-1 agonists promote weight loss, lower plasma lipids, and reduce blood pressure.43,52,53 Cardioprotective effects, ischemic conditioning, and enhanced endothelial function have also been associated with GLP-1 agonists in small clinical trials.54-57

### GLP-1 Agonists and Cardiovascular Risk Factors

In a large retrospective analysis of outpatient electronic medical records, patients with diabetes mellitus receiving exenatide lost a mean of 3.0±7.3 kg, whereas insulin-treated patients gained 0.6±9.5 kg.52 Weight reduction in the exenatide-treated cohort was associated with favorable effects on cardiovascular

<table>
<thead>
<tr>
<th>Table 2. Clinical Effects of GLP-1 Agonists</th>
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</thead>
<tbody>
<tr>
<td><strong>GLP-1 Agonists</strong></td>
</tr>
<tr>
<td>-------------------------------------------</td>
</tr>
<tr>
<td><strong>Glycemic control</strong></td>
</tr>
<tr>
<td>Hemoglobin A1C</td>
</tr>
<tr>
<td>Postprandial effects</td>
</tr>
<tr>
<td>Gastric emptying and appetite</td>
</tr>
<tr>
<td>Established cardiovascular risk factor effects</td>
</tr>
<tr>
<td>Body weight</td>
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<tr>
<td>Lipid profile</td>
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<tr>
<td>Blood pressure</td>
</tr>
<tr>
<td>Cardiovascular benefits under investigation</td>
</tr>
<tr>
<td>Heart failure</td>
</tr>
<tr>
<td>Coronary artery disease</td>
</tr>
<tr>
<td>Increased ischemic conditioning</td>
</tr>
<tr>
<td>Risks and concerns*</td>
</tr>
<tr>
<td>Common ADRs</td>
</tr>
<tr>
<td>Uncommon ADRs</td>
</tr>
<tr>
<td>Safety concerns</td>
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<td></td>
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ADR indicates adverse drug reaction.

*See text for details.
risk profiles.58 Because obesity is an independent cardiovascular risk factor and many conventional hypoglycemic agents cause substantial weight gain, GLP-1 agonist therapy may be preferred in overweight patients with diabetes mellitus to mitigate cardiovascular risks.5 Furthermore, clinical trials of GLP-1 agonists demonstrate modest improvements in lipid levels following treatment, with reductions in total cholesterol, low-density lipoprotein cholesterol, triglycerides, and apolipoprotein B levels.59,60 Although improvements in plasma lipid profiles are often attributed to a direct effect of GLP-1 therapy, changes may be confounded by incretin-associated weight loss.52

GLP-1 agonist therapy appears to ameliorate hypertension as well. In a meta-analysis of 6 trials with 2171 subjects, exenatide was associated with 2 to 4 mmHg reductions in systolic blood pressure in comparison with insulin or placebo.53 A pooled analysis of the Liraglutide Effect and Action in Diabetes (LEAD) trials demonstrated similar blood pressure reductions.59 Antihypertensive effects occur before and independent of weight loss. Recent studies on the effects of liraglutide in a murine model suggest that GLP-1 antihypertensive effects may be mediated by GLP-1R–stimulated atrial natriuretic peptide secretion from atrial cardiomyocytes. Downstream effects of atrial natriuretic peptide include cGMP-mediated vasodilation, increased endothelial permeability, and renal sodium excretion.60

GLP-1 Agonists in Heart Failure

Animal Models

Preliminary data from animal models raise the possibility of a benefit in heart failure. In preclinical studies, the disruption of GLP-1 receptors in the murine heart led to diastolic heart failure, increased left ventricular (LV) end-diastolic pressures, and increased LV wall thickness.61 A 3-month course of continuous GLP-1 agonist infusion in spontaneously hypertensive heart failure–prone obese rats was associated with prolonged survival, preserved LV function, enhanced myocardial glucose uptake, and reduced apoptosis.62 GLP-1 infusion in dogs with pacing-induced cardiomyopathy resulted in significant increases in stroke volume and cardiac output.63

Clinical Data

Early clinical studies in humans have shown promise, but with conflicting findings. In a nonrandomized study of 12 patients with New York Heart Association class III/IV chronic heart failure, a continuous 12-week infusion of GLP-1 improved LV ejection fraction and 6-minute walk in comparison with 9 heart failure patients on standard therapy.64 In contrast, a randomized double-blind study of a 48-hour GLP-1 infusion in 15 patients without diabetes mellitus with less severe New York Heart Association class II to III compensated heart failure demonstrated no significant beneficial hemodynamic effects and episodes of hypoglycemia early in the infusion protocol.65 It is important to recognize the limitations of trials that use GLP-1 agonists as a continuous infusion. This formulation and route of administration may differ substantially from the commercially available injectable GLP-1 agonists approved for intermittent use in diabetes mellitus. Therefore, effects observed following GLP-1 infusions must be interpreted carefully and may not pertain to currently available incretin therapy. Furthermore, long-term outcomes of GLP-1 agonists in patients with heart failure remain unproven. Despite promising preclinical studies of DPP-IV inhibitors in animals with reduced ventricular function, a large clinical trial of saxagliptin in humans was associated with an increased rate of heart failure hospitalizations.13,14,51 Although an increased signal for heart failure was not apparent in other trials, a class effect among incretins cannot be fully excluded and caution is required.15 Still, because many traditional hypoglycemic agents are associated with fluid retention that is undesirable in the setting of heart failure, GLP-1 agonists may fill an important niche. The favorable side-effect profile of GLP-1 agonists and possible pleiotropic effects warrant additional studies in patients with diabetes mellitus and heart failure.

GLP-1 Agonists in Endothelial Dysfunction

Animal Models

Preliminary data suggest that GLP-1 agonists may improve vascular endothelial dysfunction, which is strongly associated with insulin resistance in type 2 diabetes mellitus. Preclinical studies of GLP-1 agonists in a mouse model demonstrate decreases in vascular inflammatory markers and monocyte/macrophage accumulation in the arterial wall.66

Clinical Data

In a small series of patients with diabetes mellitus and coronary disease, GLP-1 agonists were associated with improvements in vascular endothelial function and endothelial-dependent vasodilation.59 Additional trials are warranted to determine whether these molecular and cellular effects translate into meaningful clinical outcomes.

GLP-1 Agonists in Ischemia

Animal Models

GLP-1 agonists may also play a role in ischemic conditioning. Cardioprotective effects of GLP-1 therapies have been observed in animal models of myocardial ischemia, with reductions in infarct size and preserved cardiac function perhaps as a result of enhanced myocardial glucose uptake.67,68

Clinical Data

Evidence supporting GLP-1–based therapies in the setting of myocardial ischemia in humans is limited. A small nonrandomized study identified that a 72-hour infusion of GLP-1 after percutaneous coronary intervention for acute myocardial infarction was associated with significant improvements in post–myocardial infarction LV ejection fraction and wall motion in comparison with placebo.69 In another small study, GLP-1 infusion 12 hours before coronary artery bypass graft surgery was associated with less need for postoperative inotropic support and improved glycemic control in comparison with insulin.69 Most recently, several randomized trials of exenatide before reperfusion in patients with ST-segment elevation myocardial infarction undergoing urgent primary percutaneous coronary revascularization with drug-eluting
GLP-1 Agonists and Major Adverse Cardiovascular Events

Finally, and most importantly, there is some preliminary evidence to suggest that GLP-1 agonists may reduce the risk of major cardiovascular events in patients with type 2 diabetes mellitus. Pooled data from early liraglutide and exenatide trials revealed trends toward a reduction in cardiovascular events (liraglutide incidence ratio for major adverse cardiac events, 0.73; 95% confidence interval, 0.38–1.41; exenatide relative risk, 0.7; 95% confidence interval, 0.38–1.31). 70,71 A retrospective analysis of an insurance claims database observed that diabetic patients treated with exenatide had lower rates of myocardial infarction, stroke, and coronary revascularization than patients assigned to other glucose-lowering therapies. 72 Large, prospective randomized trials are ongoing to determine the long-term effects of GLP-1 agonist therapy on macrovascular outcomes and cardiovascular end points in patients with diabetes mellitus. The ELIXA (lixisenatide) trial will evaluate cardiovascular outcomes with GLP-1 therapy following acute coronary syndromes. Results from the EXSCEL (weekly exenatide), LEADER (liraglutide) and REWIND (dulaglutide) trials will provide valuable insight into the long-term cardiovascular impact of routine GLP-1 agonist therapy in diabetes mellitus.

Concerns About GLP-1 Agonists: A Focus on Safety

Despite the many attractive features of incretin therapy, concerns remain. Shortly after the release of exenatide, postmarketing reports of patients with spontaneous pancreatic tumors were submitted to the FDA, leading to warnings on the product label. 73 Preclinical reports of neoplastic effects of GLP-1 agonists on pancreatic tissues also surfaced. GLP-1 is known to promote focal proliferation of the exocrine pancreas in animal studies. Exenatide therapy has been associated with the development of pancreatic mucinous metaplasia, atypia, and neoplasia in mice, although animal studies of liraglutide failed to demonstrate similar associations. 74,75

Limited data exist to support any elevated incidence of pancreatitis associated with incretins in humans. A small histology study of human tissue from organ donors with type 2 diabetes mellitus demonstrated pancreatic proliferation and dysplasia in subjects who had been chronically treated with incretin therapy. 76 A study based on the FDA adverse events database identified 6- to 10-fold increases in pancreatitis associated with sitagliptin and exenatide, and a 3-fold increase in pancreatic cancer. 77 A case-control study of patients with diabetes mellitus who were hospitalized for acute pancreatitis reported that concurrent use of GLP-1 therapy was associated with a 2-fold increased risk for pancreatitis (odds ratio, 2.24) after adjusting for available confounders. 78 These studies were retrospective, were subject to significant reporting bias, and failed to adjudicate events to ensure consistent definitions of the safety end points. In contrast, data from multiple claims databases identified no increased risk of hospitalization for acute pancreatitis among diabetic patients receiving exenatide or sitagliptin. 79,82 Furthermore, diabetes mellitus is independently associated with a 2- to 3-fold greater risk of acute pancreatitis in comparison with nondiabetic cohorts, providing an alternative explanation for the sporadic reports of pancreatitis among patients on incretin therapies. 80,83 Finally, despite conflicting evidence from retrospective studies, prospective trials of GLP-1 agonists do not report an increased risk of pancreatitis or pancreatic malignancy. 77,78,45,49,50

Adverse effects of long-acting GLP-1 agonist therapy on the thyroid are also of concern. Sustained liraglutide exposure promotes C-cell hyperplasia and medullary thyroid cancer in rodents, although evidence supporting an oncogenic effect in humans is lacking. 84,85 Despite FDA approval, liraglutide carries a black-box warning about the risk of thyroid C-cell tumors and is contraindicated in patients with a family history of medullary thyroid cancer or the Multiple Endocrine Neoplasia syndrome Type 2. 86 Furthermore, a registry has been established to monitor the long-term incidence of medullary thyroid cancer associated with liraglutide therapy.

Recent evidence from multiple clinical trials suggests that the GLP-1 agonist class is associated with modest increases in heart rate of ≈2 beats per minute. 38,42,49 The mechanistic basis and clinical impact of this potentially undesirable cardiovascular effect has not been defined, although there are no data to suggest any negative consequences of the observed increase in pulse rate.

Some controversy regarding GLP-1 agonist safety is likely to continue until long-term safety data are available. Prospective studies are warranted to determine the extent, if any, of the potential adverse effects of long-term GLP-1 agonist therapy.

Conclusions

Diabetes mellitus–related cardiovascular complications remain a significant cause of morbidity and mortality, despite the use of conventional hypoglycemic agents. New pharmacological agents are urgently needed. Incretin therapies represent a novel approach to glycemic control by restoring multiple pathophysiological defects of diabetes mellitus. Incretin therapies augment glucose-stimulated insulin secretion, reduce glucacon production, and limit β-cell apoptosis in animal models. Among incretins in clinical practice, GLP-1 agonists provide considerable reductions in HbA1C with minimal risk of hypoglycemia. Consequently, GLP-1 agonists are positioned second-line after metformin in consensus algorithms for diabetes mellitus management, despite cost, injectable formulation, frequent gastrointestinal side effects, and the previously addressed safety concerns. 87 In addition to enhanced glycemic control, GLP-1 agonists demonstrate...
antihypertensive properties, can improve lipid profiles, and cause weight loss, which may decrease insulin resistance and further improve glycemic control. Small clinical trials demonstrate improved endothelial function and some promising cardioprotective benefits. Studies of GLP-1 agonists in patients with acute myocardial ischemia warrant further investigation in larger patient cohorts undergoing percutaneous coronary interventions. There is a dearth of data regarding the outcomes of GLP-1 agonists in patients with diabetes mellitus and heart failure, and clinical trials are necessary to establish safety. Although some evidence suggests that GLP-1 agonist therapy is associated with reductions in cardiovascular events, the related DPP-IV inhibitor drug class appears to offer no such benefit. Large trials of GLP-1 agonists currently underway will provide valuable long-term data on cardiovascular safety and clinical outcomes. Theoretical risks of pancreatitis have caused controversy, but available evidence supports the safety of GLP-1 agonist use. At present, identifying the optimal candidates for GLP-1 therapy necessitates an individualized assessment of glycemic control, medical comorbidities, and the presence of cardiovascular risk factors. GLP-1 agonist therapy can delay insulin initiation or reduce insulin doses. There may be a role for GLP-1 agonists in patients with prediabetes and cardiovascular risk factors, but this requires further study.

In conclusion, cardiovascular risk factor reduction offers a compelling rationale to incorporate GLP-1 agonist therapy early in the management of diabetes mellitus in patients at risk for cardiovascular disease.

Disclosures

Dr Schwartzbard has received payment for the development of educational presentations from Takeda. The other authors report no conflicts.

References


Key Words: cardiovascular diseases ▪ diabetes mellitus ▪ obesity ▪ pharmaceutical preparations ▪ prevention & control
Glucagon-Like Peptide-1 Receptor Agonists for Diabetes Mellitus: A Role in Cardiovascular Disease
Nathaniel R. Smilowitz, Robert Donnino and Arthur Schwartzbard

Circulation. 2014;129:2305-2312
doi: 10.1161/CIRCULATIONAHA.113.006985
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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