The artificial pancreas: Incremental improvements towards an automated closed-loop insulin delivery system in type 1 diabetes

Editorial

Type 1 diabetes (T1D) is a multifactorial disease and both, an autoimmune disease and a metabolic disorder. The disease itself is characterized by an irreversible T-cell-mediated destruction of β-cells in the islets of Langerhans of the pancreas, resulting in insulin deficiency. Insulin deficiency leads to disturbances in blood glucose homeostasis, hyperglycemia, increased gluconeogenesis and lipolysis, elevated metabolism of free fatty acids and the generation of ketone bodies. Life-threatening hyperglycemia and diabetic ketoacidosis are the primary clinical signs of T1D while micro vascular and macro vascular complications are the long-term burdens of the disease. Both, immunologic and metabolic changes often far precede the clinical onset and diagnosis of the disease.

The absolute deficiency of insulin secretion in T1D patients requires insulin injections to maintain carbohydrate metabolism and achieve glycemic control. Unfortunately, to date, no cure has been identified to prevent, postpone the onset, halt the further progression or reverse the course of the disease.1 Thus, insulin-replacement therapy is the life-saving, first-line treatment for T1D and remains the widely accepted standard of care.2 Multiple daily injections or continuous subcutaneous insulin delivery using insulin pumps is the means by which T1D patients aim to restore carbohydrate metabolism and achieve glycemic control. Indeed, multiple studies have demonstrated that intensive insulin therapy and tight glycemic control may prevent acute and chronic complications and reduce morbidity and mortality in T1D patients.3-4 However, even intensive insulin-replacement regimens are not always sufficient in restoring euglycemia and achieve recommended HbA1c levels.5,6 Moreover, they are often associated with the risk of both, symptomatic and life-threatening hypoglycemia.5-11

It is for these reasons that over the last 40 years major efforts were underway, both in academia and industry, to develop and advance novel strategies and technologies in order to restore strict glycemic control and reduce hyperglycemia without increasing the risk for hypoglycemia in patients diagnosed with T1D. More specifically, a significant amount of research, resources and talent were directed towards an automated closed-loop insulin delivery system that will automate the delivery of insulin linked to actual blood glucose levels has again gotten traction in the scientific community. This multi-device technology is based on using a control algorithm to autonomously, automatically, and continually adjust subcutaneous delivery of insulin based on real-time, subcutaneous glucose sensor data.12,13 Its ultimate objective is to relieve T1D patients of the burden of diabetes self-management.

Hybrid closed-loop systems which combine user-delivered pre-meal boluses with automatic inter-prandial insulin delivery were the first systems developed along this lines.20 In 2016, the Center for Devices and Radiological Health of the Food and Drug Administration approved the first hybrid closed-loop system: the Medtronic MiniMed 670G System. According to the manufacturer the MiniMed 670G System. According to the manufacturer the MiniMed 670G system is intended for continuous delivery of basal insulin (at preset glucose levels).16,17 Safety features such as threshold-suspend and predictive low glucose management insulin pumps provided an important and significant step in the development of device technology. The respective clinical applications appear to be safe and address hypoglycemia; however, using such devices still does not sufficiently address hyperglycemia, the major issue in T1D patients.

More recently, with major advances in microelectronics, glucose sensor technology and insulin delivery systems, the old idea of developing an “artificial pancreas” or a “closed-loop insulin delivery system” that will automate the delivery of insulin linked to actual blood glucose levels has again gotten traction in the scientific community. This multi-device technology is based on using a control algorithm to autonomously, automatically, and continually adjust subcutaneous delivery of insulin based on real-time, subcutaneous glucose sensor data.12,13 Its ultimate objective is to relieve T1D patients of the burden of diabetes self-management.

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Studies have shown that hybrid closed-loop systems are reliable and safe to be used in adults and adolescents.21,22 These systems allow patients to lower mean blood glucose levels without increasing the risk of hypoglycemia and they help to improve the proportion of time spent in a normal and healthy glucose range. In addition, extensive studies under controlled laboratory settings and several randomized, controlled outpatient studies have been completed to test various
insulin-only artificial pancreas closed-loop systems. They all demonstrated that these systems have the potential to improve glucose control and reduce the risk of hypoglycemia. Studies that investigate the potential of bi-hormonal bionic pancreas systems that combine continuous glucose monitoring and algorithms to automatically administer both insulin and glucagon are thus already underway.

In conclusion, over the last 40 years, considerable progress has been made towards developing continuous glucose sensors, automated insulin delivery devices, and closed-loop artificial pancreas systems that are clinically meaningful and beneficial to a subset of T1D patients under specific conditions. Despite considerable progress, however, many technical, practical and clinical challenges remain towards the development of a fully automated, autonomous closed-loop artificial pancreas system. To date, studies assessing safety and efficacy of closed-loop artificial pancreas systems involving patients under at-home, free-living conditions are still very limited in number. Moreover, it remains to be established whether a closed-loop artificial pancreas system is feasible, efficacious, and safe to be used in adolescents and children. As important, to fully determine the potential benefit of such technology on restoring glycemic control, normalizing HbA1c levels, and avoiding acute and chronic complications of diabetes, corresponding data will have to be generated in large-scale clinical trials with extended follow-up periods. Last but not least, delivering small technological advancements and providing incremental progress over decades by no means guarantee market acceptance or predict market penetration of a product. While a mature closed-loop artificial pancreas system may be attractive, practical and beneficial for a certain sub-segment of the T1D patient population, it may be completely unattractive, burdensome, and ignored by others. Thus, it remains to be seen how the individual T1D patient, the T1D community, the healthcare providers and the market-place will embrace the closed-loop artificial pancreas technology when it fully matures.

At last, the question remains whether academic talent, resources and funds should continue to be deployed towards incremental improvements of currently existing glucose sensing, glucose monitoring, insulin delivery and closed-loop artificial pancreas technologies, or whether the T1D community would be better served with investments into transformative research and discoveries. For both, academic T1D researchers and T1D funding agencies it may be time to halt and once more reflect and consider the ultimate needs of the T1D community. While incremental improvements in closed-loop artificial pancreas technology may undoubtedly benefit and improve quality of life and psychological well-being of a subset of T1D patients, a transformative discovery holds the promise of a cure under at-home, free-living conditions.

Acknowledgment

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Conflicts of interests

Authors declare that there is no conflict of interest.

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