Case Report: Managing Pregnancy With Type 1 Diabetes Using a Do-It-Yourself Artificial Pancreas System

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The stakes are high when pregnancies are complicated by type 1 diabetes. In addition to the maternal risks, there are numerous fetal complications that can result from diabetes, including spontaneous abortion, fetal anomalies, neonatal birth trauma, macrosomia, neonatal hypoglycemia, hyperbilirubinemia, and fetal demise (1). Consequently, the American Diabetes Association (ADA) recommends stringent glycemic targets in pregnant women with type 1 diabetes to prevent adverse maternal and fetal outcomes.

Recommendations include self-monitoring of both fasting and postprandial blood glucose and a target A1C of <6% without significant hypoglycemia. Preprandial glucose testing is also recommended in women with pregestational diabetes using insulin pumps or basal-bolus therapy so that premeal rapid-acting insulin doses can be adjusted (2). The following individual glucose targets are recommended for type 1 diabetes: fasting glucose <90 mg/dL, 1-hour postprandial glucose <130–140 mg/dL, and 2-hour postprandial glucose <120 mg/dL (2).

These strict glycemic targets are difficult to achieve, especially given the insulin resistance commonly observed during the second and third trimesters of pregnancy. Indeed, women with gestational and pregestational diabetes have average A1C levels ranging from 7.25 to 8.15%, values that are considerably higher than ADA targets during pregnancy (3). Despite the availability of continuous glucose monitoring (CGM) systems since 1999, none have been approved by the U.S. Food and Drug Administration (FDA) for use in pregnancy. Moreover, no insulin pumps or hybrid-closed loop (HCL) automated insulin delivery systems have been approved for use during pregnancy. The lack of FDA-approved diabetes management technologies poses a significant limitation to pregnant women with type 1 diabetes.

Individuals in the type 1 diabetes community have developed open-source software and hardware to create a do-it-yourself artificial pancreas system (DIY APS) that allows for automated insulin dose adjustments. These systems include algorithms that, when coupled with an insulin pump and CGM system, mimic pancreatic β-cell function (4). A DIY APS requires a processor capable of receiving insulin pump and CGM data and an algorithm to control the rate of insulin delivery using a compatible insulin pump (5). With these systems, many patients with type 1 diabetes have reported improvements in their quality of life, more time in the target glucose range, better sleep, less frequent and less severe hypoglycemia, lower A1C, greater confidence in diabetes management, more energy, and fewer mood swings (3).

The use of an innovative and patient-developed DIY APS during pregnancy has not been reported previously. Herein, we present a unique case of type 1 diabetes management during pregnancy in which a DIY APS where the "Loop" algorithm on an iPhone interface was used (5). The patient provided written informed consent for the publication of this case report.

Case Presentation

This case involves a first pregnancy of a 30-year-old woman with type 1 diabetes since the age of 6 years. Before conception, she used a DIY APS with a Medtronic pump and Dexcom CGM system that allowed for her to manage diabetes using the Loop application that she built and installed on her iPhone. Sensor glucose data, insulin doses, and carbohydrate intake were visible through the Loop application and Apple Health app.

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She had optimized her glycemic control before conception, with an A1C of 6.0%. During the month before conception, her overall mean sensor glucose was 134 mg/dL with a coefficient of variation (CV) of 41%, indicating healthy glycemic control. During this time, her CGM metrics indicated 77% of time in range (TIR; 70–180 mg/dL), 5% of time <70 mg/dL, and 17% of time >180 mg/dL.

During pregnancy, she noted an increase in her insulin requirements. Table 1 lists the insulin-to-carbohydrate ratios and insulin sensitivity factors she used during each trimester of pregnancy. Her A1C levels remained ≤5.7% throughout the pregnancy. She maintained optimal glycemic control, with 87% TIR in the third trimester. Details of her CGM metrics are listed in Table 2. The patient was managed by the Maternal Fetal Medicine Clinic at Yale New Haven Hospital by a team of physicians, nurses, and diabetes educators knowledgeable in type 1 diabetes management.

The patient presented for induction of labor at 39 weeks' gestation and delivered a healthy female infant via cesarean section due to arrest of descent. The newborn weighed 2,910 g (16th percentile for age based on Centers for Disease Control and Prevention [CDC] growth charts) and measured 49.53 cm in length (54th percentile for age based on CDC growth charts), and thus her size was appropriate for gestational age.

The infant required temporary monitoring in the Neonatal Intensive Care Unit for hypoglycemia, which resolved within 24 hours of birth with a combination of breast milk and formula feeding. The infant was otherwise healthy and both mother and baby were discharged on the third day after delivery.

Questions

1. What are the challenges of type 1 diabetes management during pregnancy?
2. How can we incorporate the use of diabetes technology during pregnancy?
3. What are the advantages of using a DIY APS in pregnancy?

Commentary

Although the increased risk of adverse pregnancy outcomes in women with type 1 diabetes is well established, FDA approval of the use of diabetes technologies in this population is lacking. The CONCEPTT (Continuous Glucose Monitoring in Women With Type 1 Diabetes in Pregnancy Trial) showed that use of real-time CGM during pregnancy in women with type 1 diabetes was associated with improved neonatal outcomes compared with using multiple fingerstick blood glucose measurements (6). However, in the United States, only 36% of the 214 pregnant or recently pregnant women who participated in the T1D Exchange clinic registry between 2010 and 2013 reported using CGM (7). Despite the potential benefits of CGM, the FDA has not approved the use of these devices in pregnancy. Further, newly developed HCL systems that have improved time in healthy glucose ranges in nonpregnant individuals with type 1 diabetes have not been approved for use during pregnancy. These currently available HCL systems do not allow for individuals to set pregnancy-specific targets, thus limiting options for insulin-dependent women who become pregnant. Further, glucose targets in the commercially available HCL systems are not customizable and are typically too high for pregnancy.

Although DIY APS technology has not been formally studied in pregnant women with diabetes, it provides the necessary flexibility in establishing individualized

TABLE 1 A1C Levels and Insulin Doses at the End of Each Trimester of Pregnancy

Parameters	1st Trimester (Weeks 1–12)	2nd Trimester (Weeks 13–26)	3rd Trimester (Weeks 27–40)
A1C, %	5.7	5.7	5.5
Insulin-to-carbohydrate ratio	1 unit to 13–14 g	1 unit to 10–12 g	1 unit to 8 g
Insulin sensitivity factor	1 unit to 75–80 mg/dL	1 unit to 65–85 mg/dL	1 unit to 45–65 mg/dL
Total daily bolus insulin, units/day	8.5	11.3	15.5
Total daily basal insulin, units/day (%)	17 (67)	21 (65)	32 (67)
Total daily insulin, units/day	25.5	32.3	47.5

TABLE 2 Sensor Glucose Metrics During Each Trimester of Pregnancy Using Recommended Pregnancy-Specific Target Ranges (10)

Trimester	Mean Sensor Glucose, mg/dL	Sensor Glucose CV, %	% Time <54 mg/dL	% Time <63 mg/dL	% Time in Range (64–140 mg/dL)	% Time 141–250 mg/dL	% Time >250 mg/dL	Sensor Usage, %
1	127 ± 49	38	0.9	3.7	62.8	31.6	1.9	93
2	123 ± 46	37	2.1	4.6	66.0	27.8	1.6	96
3	112 ± 37	33	1.1	3.3	76.5	19.6	0.7	95

Sensor glucose metrics for each trimester of pregnancy are presented. Excellent sensor usage (>90%) occurred throughout the pregnancy. Of note, while pregnancy-specific targets are presented in the table, the overall time spent in the target range of 70–180 mg/dL through the entire pregnancy was 87%.

target ranges and automatic adjustments to basal rates when blood glucose levels are anticipated to rise above or fall below prespecified targets, thus helping users improve their TIR with less thought, less effort, and the potential for improved glycemic control and better sleep (8,9). The degree of individualization possible with this type of technology is greater than will be achievable with commercial systems in the near future. The benefits of DIY APS systems should be balanced with risks, including the lack of a formal body to address technical issues that may arise, making DIY APS users largely responsible for finding solutions through the online community, as well as potential issues with lack of support or knowledge from their diabetes provider.

Consensus recommendations state that pregnant women with type 1 diabetes should have >70% TIR (63–140 mg/dL), <25% of time above range (>140 mg/dL), and 5% of time below range (<4% of time <63 mg/dL and <1% of time <54 mg/dL) (10). Our patient was able to meet these targets during the third trimester and reported improved sleep and less diabetes-related anxiety throughout her pregnancy. Large-for-gestational-age infants are more commonly observed in mothers who have sustained hyperglycemia during pregnancy. Therefore, it is noteworthy that the opposite was true in this patient's infant, whose weight was at the 16th percentile and length was at the 54th percentile. Normal weight in this baby suggests that maternal blood glucose levels were not substantially increased.

Using a DIY APS requires a high level of motivation and a strong understanding of diabetes technology. Those who choose to use this type of technology tend to be very actively engaged in and adherent to their diabetes management regimen. Hence, a DIY APS may not be appropriate for the general type 1 diabetes population. Nevertheless, our patient's experience illustrates that these systems can be effectively used to meet and maintain safe glucose levels throughout pregnancy.

Clinical Pearls

- Pregnant women have the strictest glycemic targets of any group with diabetes, yet no CGM or insulin pump technology is FDA-approved for this population.
- Some women with type 1 diabetes who become pregnant have chosen to use a DIY APS to achieve these targets because of the ability such systems afford to set individualized target glucose ranges and insulin dose settings with more ease and flexibility than commercially available insulin pump and HCL systems.
- Enthusiasm for DIY APS technology continues to grow in the diabetes online community, and further studies are needed to support its use and facilitate more widespread acceptance.

DUALITY OF INTEREST

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AUTHOR CONTRIBUTIONS

A.R.W., T.A., and L.M.N. wrote the manuscript. M.H. cared for the patient during pregnancy and provided data for the case report. L.M.N. conceived the idea for the case report. W.V.T. and M.H. reviewed and edited the manuscript before submission. L.M.N. is the guarantor of this work and, as such, had full access to all the data and takes full

responsibility for the integrity of data and the accuracy of data analysis.

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