OBSTETRICS

Software-guided insulin dosing improves intrapartum glycemic management in women with diabetes mellitus

Cheryl Dinglas, DO; Jolene Muscat, MD; Tracy Adams, MD; Virginia Peragallo-Dittko, RN; Anthony Vintzileos, MD; Hye J. Heo, MD

BACKGROUND: During labor, maintenance of maternal euglycemia is critical to decrease the risk of neonatal hypoglycemia and associated morbidities. When continuous intravenous insulin infusion is needed, standardized insulin dosing charts have been used for titration of insulin to maintain glucose in target range. The GlucoStabilizer software program (Indiana University Health Inc, Indianapolis, IN) is a software-guided insulin dosing system that calculates the dose of intravenous insulin that is needed based on metabolic parameters, target glucose concentration, and an individual's response to insulin. Although this tool has been validated and shown to reduce both hypoglycemia and errors in critical care settings, the utility of this software has not been examined in obstetrics.

OBJECTIVE: The purpose of this study was to determine whether the use of intravenous insulin dosing software in women with pregestational or gestational diabetes mellitus that requires intrapartum insulin infusion can improve the rate of glucose concentration in target range (70—100 mg/dL; 3.9—5.5 mmol/L) at the time delivery.

STUDY DESIGN: We performed a retrospective cohort study comparing laboring patients with diabetes mellitus that required insulin infusion who were dosed by standard insulin dosing chart vs the GlucoStabilizer software program from January 2012 to December 2017. The GlucoStabilizer software program, which was implemented in May 2016, replaced the standard intravenous insulin dosing chart. Inclusion criteria were women with pregestational or gestational diabetes mellitus who were treated with an intravenous insulin infusion intrapartum for at least 2 hours. Maternal characteristics, glucose values in labor, and neonatal outcomes were extracted from delivery and neonatal records. The primary outcome was the percentage of women who achieved the target glucose range (defined as a blood glucose between 70—100 mg/dL; 3.9—5.5 mmol/L) before delivery. Parametric and nonparametric statistics were used to compare both groups; a probability value of $<.05$ was considered statistically significant.

RESULTS: We identified 22 patients who were dosed by a standard insulin dosing chart and 11 patients who were dosed by the GlucoStabilizer software program during intrapartum management. The GlucoStabilizer software program was superior in achieving glucose values in target range at delivery (81.8% vs 9.1%; $P<.001$) compared with standard insulin dosing without increasing maternal hypoglycemia (0% vs 4.3%; $P=.99$). Patients whose insulin dosing was managed by the GlucoStabilizer software program also had lower mean capillary blood glucose values compared with the standard insulin infusion (102.9±5.9 mg/dL [5.7±0.33 mmol/L] vs 121.7±5.9 mg/dL [6.8±0.33 mmol/L]; $P=.02$). Before the initiation of the infusion, both groups demonstrated mean capillary blood glucose values outside of target range (122.6±8.8 mg/dL [6.7±0.49 mmol/L] for the GlucoStabilizer software program vs 131.9±10.1 mg/dL [7.3±0.56 mmol/L] for standard insulin treatment group; P=not significant). There were no significant differences in baseline maternal characteristics between the groups or neonatal outcomes.

CONCLUSION: This study is the first to demonstrate that the use of software-guided intravenous insulin dosing in obstetrics can improve intrapartum glycemic management without increasing hypoglycemia in women with both pregestational and gestational diabetes mellitus that is treated with an insulin infusion.

Key words: diabetes mellitus, glycemia, hyperglycemia, hypoglycemia, software-guided insulin dosing

The prevalence of diabetes mellitus during pregnancy has increased in recent years,[1] which has led to a large number of studies addressing preventive measures, antepartum interventions, and postpartum treatment of these patients.[2-5] However, studies that have addressed intrapartum glucose management are scarce. During labor and delivery, the goal is to maintain maternal glucose concentration in a target range to avoid both hypo- and hyperglycemic events. When necessary, blood glucose is managed with the use of a continuous intravenous insulin infusion that is dosed from a standard insulin dosing chart based on glucose values (Figure 1).[6]

The GlucoStabilizer software program (Indiana University Health Inc, Indianapolis, IN) is a software-guided insulin dosing system that has been cleared by the US Food and Drug Administration to calculate the dose of intravenous insulin that is needed to maintain capillary blood glucose concentration effectively in the target range while reducing hypoglycemia and reducing errors. An annual technology license includes service, support, and core system maintenance; 1-time costs are associated with installation, training, and interfacing. GlucoStabilizer is a trademark of Indiana University Health Inc, under license. The program calculates the insulin dose based on target glucose range and adjusts rates based on an individual's response to treatment, with the use of an insulin sensitivity factor.[7] In critical care

Cite this article as: Dinglas C, Muscat J, Adams T, et al. Software-guided insulin dosing improves intrapartum glycemic management in women with diabetes mellitus. Am J Obstet Gynecol 2018;219:191.e1-6.

0002-9378/$36.00

https://doi.org/10.1016/j.ajog.2018.05.003

AJOG at a Glance

Why was this study conducted?

This study was conducted to validate the superiority of the GlucoStabilizer (Indiana University Health Inc, Indianapolis, IN) software–based insulin dosing program over standard insulin chart-based protocols in intrapartum glycemic treatment of women with diabetes mellitus that requires intravenous insulin infusion.

Key Findings

In women with diabetes mellitus that requires intrapartum insulin infusion, the use of the GlucoStabilizer software–guided insulin dosing program improves the rate of glucose concentration in target range (70–100 mg/dL; 3.9–5.5 mmol/L) at the time of delivery, without increasing hypoglycemic episodes.

What does this add to what is known?

This is the first study to demonstrate the utility of a software-guided insulin dosing program in intrapartum treatment of women with pregestational and gestational diabetes mellitus with the ability to individualize insulin dosing based on an individual's response to treatment.

settings, use of GlucoStabilizer software has been validated to be superior to standard paper protocols for insulin dosing in decreasing glucose variability, improving glycemia, and minimizing hypoglycemia.[7-10] Juneja et al[7] performed a retrospective study of 2398 patients who were admitted to the intensive care unit and who required an insulin infusion, assessing glycemic levels before and after implementation of the GlucoStabilizer software program. The percentage of measurements <110 mg/dL (6.1 mmol/L) in the intensive care units in the 3 months before introduction of the GlucoStabilizer program was 31.5%, compared with 51.5% in the 3 months after introduction of the software (P<.001).

With the established safety and efficacy of software-guided insulin infusion dosing in critical care settings, our institution implemented the use of the GlucoStabilizer software program for insulin infusion dosing in the intrapartum period in women who require an insulin infusion in labor. We performed a retrospective study comparing intrapartum glycemia in women who were treated after implementation of the GlucoStabilizer software program vs a standard intravenous insulin dosing chart before implementation at our institution.

FIGURE 1
Standard insulin infusion chart

Plasma/Capillary Glucose (mg/dL)	Infusion Rate (U/hr)
<80	Insulin off
80-100	0.5*
101-140	1.0
141-180	1.5
181-220	2.0*
>220	2.5*

*Intravenous bolus of 2-5 units when the rate increases

Reprinted from *Creasy & Resnick's maternal fetal medicine: Principles and practice, 7th Edition* (p 1020), by TR Moore, P Catalano, S Hauguel-DeMouzon, Philadelphia, PA: Saunders/Elselvier. 2014, with permission

The standard insulin infusion chart used in our institution before implementation of the software-guided insulin dosing system.

Dinglas et al. GlucoStabilizer insulin dosing and intrapartum glycemic management. Am J Obstet Gynecol 2018.

Materials and Methods

This was a retrospective cohort study that evaluated pregnant patients with diabetes mellitus who required an insulin infusion for glycemic management in the intrapartum period from January 2012 through December 2017. At New York University Winthrop Hospital, laboring patients who require an insulin infusion for intrapartum glycemic management had been treated by a standard paper intravenous insulin dosing chart (Figure 1)[6] until May 2016, at which time the GlucoStabilizer software program was implemented.

The GlucoStabilizer software-guided system is easy to operate, runs on a hospital's existing computer system and can be interfaced with a hospital information system for documentation. It is menu driven and provides alerts for nursing staff for when to draw the next point-of-care capillary blood glucose measurement and how to adjust the rate based on the patient's glucose value that has been entered into the system.[7,8] Figure 2 gives an example of a patient whose insulin was dosed with the GlucoStabilizer software program.

Using our electronic medical and pharmacy database, we identified a total of 39 patients with a diagnosis of pregestational or gestational diabetes mellitus that required intrapartum intravenous insulin infusion at the time of delivery during the study period. The intravenous insulin requirements for 23 patients were dosed with the use of standard insulin dosing charts, and 16 patients were dosed with the use of the GlucoStabilizer software program. We excluded patients who were treated with an intravenous insulin infusion for <2 hours because this could be insufficient time to demonstrate adjustments in

FIGURE 2
Example patient's insulin doses calculated by the GlucoStabilizer (Indiana University Health Inc, Indianapolis, IN) software program

Date	Glucose	Multiplier	Driprate (A)
11/09/2017 08:25:51	209	0.02	3
11/09/2017 09:27:58	222	0.03	4.9
11/09/2017 10:30:15	194	0.04	5.4
11/09/2017 11:31:11	149	0.05	4.5
11/09/2017 12:32:59	118	0.06	3.5
11/09/2017 13:32:47	111	0.07	3.6
11/09/2017 14:37:56	78	0.07	1.3
11/09/2017 15:37:41	86	0.07	1.8
11/09/2017 16:29:08	89	0.07	2
11/09/2017 17:36:03	86	0.07	1.8
11/09/2017 18:37:02	88	0.07	2
11/09/2017 19:44:36	97	0.07	2.6
11/09/2017 20:48:09	89	0.07	2
11/09/2017 21:49:35	111	0.07	3.6
11/09/2017 22:59:12	114	0.08	4.3
11/10/2017 00:21:30	103	0.09	3.9
11/10/2017 01:23:31	89	0.09	2.6
11/10/2017 02:33:26	83	0.09	2.1
11/10/2017 03:36:46	94	0.09	3.1
11/10/2017 04:53:07	80	0.09	1.8
11/10/2017 06:10:06	78	0.09	1.6
11/10/2017 07:29:25	92	0.09	2.9
11/10/2017 09:48:39	75	0.09	1.4

Glucose: listed in milligrams/deciliter
Multiplier: insulin sensitivity factor
Driprate (A): Insulin Administered in units/hour

An example of a patient's insulin doses calculated by the GlucoStabilizer software program that demonstrates the glucose reading, insulin sensitivity factor (shown as multiplier), and the calculated drip rate administered.

Dinglas et al. GlucoStabilizer insulin dosing and intrapartum glycemic management. Am J Obstet Gynecol 2018.

insulin dose and response to such adjustments. For our analysis, data for 22 patients whose insulin infusions were dosed by a standard insulin dosing chart were compared with 11 patients whose insulin infusions were dosed by a software-guided insulin infusion dosing system, the GlucoStabilizer software program. Point-of-care capillary blood glucose concentration was measured hourly for both groups during the time of treatment. An intrapartum glucose target range of 70−100 mg/dL (3.9−5.5 mmol/L) was used during both study periods. We used an upper target threshold of 100 mg/dL (5.5 mmol/L), with other studies demonstrating that lower intrapartum plasma glucose levels may be associated with a lower incidence of neonatal hypoglycemia.[11,12]

Maternal characteristics, glucose values during labor, and neonatal outcomes were extracted from delivery and neonatal records. The primary outcome was the percentage of women who achieved glucose values in the target range defined as capillary blood glucose measurements of 70−100 mg/dL (3.9−5.5 mmol/L) before delivery. We chose the percentage of women who achieved glucose values in the target range as our primary outcome because it serves as a test or measure to establish the superiority of the GlucoStabilizer software program over standard insulin dosing chart-based protocols in intrapartum management. Validation of the use of a software-guided insulin dosing program in obstetrics has not been reported previously. We undertook a sample size analysis to evaluate a difference in the primary outcome (proportion of subjects with optimal glucose values during labor) with the following assumptions: type I error of 0.05 for a 2-sided test, type II error of 0.1 (power of 90%), baseline proportion of women with optimal glucose values before the intervention of 10%, and the proportion of women with optimal glucose values after to the intervention of 75%. With these assumptions, we would require a study size of 10 subjects per group (20 total) to demonstrate a clinically meaningful difference in the primary outcome.

Secondary outcomes included mean capillary glucose values (milligram per deciliter) while being treated with an insulin infusion, episodes of maternal hypoglycemia defined as glucose <60 mg/dL (3.3 mmol/L), and neonatal outcomes (which included mean initial neonatal glucose values after delivery (milligrams per deciliter), admission to neonatal intensive care unit secondary to hypoglycemia, diagnosis of respiratory distress syndrome, or hyperbilirubinemia that required phototherapy). Parametric and nonparametric statistics were used to compare both groups; a probability value of <.05 was statistically significant. Fisher's Exact test for categoric variables and 2 independent samples *t*-test for continuous variables were used.

Results

In total, 22 patients who were dosed with the use of a standard insulin dosing chart were compared with 11 patients who were dosed by the GlucoStabilizer software program in our analysis. There were no significant differences in baseline characteristics between the 2 groups with regards to maternal age, prepregnancy body mass index, type of diabetes mellitus, gestational age at delivery, or treatment with insulin (Table 1). Before the initiation of the intravenous insulin infusion, both groups had similar mean capillary blood glucose values outside of target range (standard insulin chart, 131.9±10.1 mg/dL [7.3±0.56 mmol/L] vs the GlucoStabilizer software program, 122.6±8.8 mg/dL [6.7±0.49 mmol/L]; *P*=not significant; Table 2).

After initiation of the intravenous insulin infusion, software-guided insulin dosing by the GlucoStabilizer software program achieved mean capillary glucose values much closer to the target range than by standard insulin chart based dosing (the GlucoStabilizer software program, 102.9±5.9 mg/dL [5.7±0.33 mmol/L] vs standard insulin chart, 121.7±5.9 mg/dL [6.8±0.33 mmol/L]; *P*=.02; Table 2). Additionally, 81.8% of patients who were dosed by the GlucoStabilizer software program achieved capillary blood glucose values in the target range before delivery, compared with 9.1% of patients who were dosed by standard insulin charts with a probability value of .0001 (Table 2). Figure 3 shows that the mean capillary blood glucose value 1 hour before delivery was 122 mg/dL (6.8 mmol/L) with standard insulin chart dosing compared with 92.5 mg/dL (5.1 mmol/L) with the GlucoStabilizer software program, with a probability value of <.05. In addition, we performed an intention-to-treat analysis in which we included all patients who received standard insulin chart dosing vs the GlucoStabilizer software program without excluding those who were treated with the infusion for <2 hours. The analysis includes 23 patients who were dosed with standard insulin chart dosing and 16 patients who were dosed with the GlucoStabilizer software program. The

TABLE 1
Baseline characteristics of patients included in the study

Patient characteristics	Standard insulin infusion (n=22)	GlucoStabilizer software program (Indiana University Health Inc, Indianapolis, IN; n=11)	*P* value[a]
Age, y[b]	30.1±5.1	32.5±2.5	.18
Prepregnancy body mass index, kg/m^2[b]	29.6±7.8	34.7±9.6	.12
Gestational age at delivery, wk[b]	36.6±2.6	35.5±2.5	.11
Diabetes mellitus type, n (%)			.96
1	9 (41.0)	5 (45.4)	
2	7 (31.8)	3 (27.3)	
Gestational	6 (27.2)	3 (27.3)	
Diabetes mellitus managed by insulin, n (%)	17 (77.3)	10 (90.9)	.64

[a] Fisher's Exact test for categoric variables; 2 independent samples *t*-test for continuous variables; [b] Values expressed as mean ±standard deviation.

Dinglas et al. GlucoStabilizer insulin dosing and intrapartum glycemic management. Am J Obstet Gynecol 2018.

results still demonstrate that the percentage of patients with glucose values within the target at delivery is still significant (13% vs 75%), with a probability value of .002.

Along with the ability to maintain glucose in target range, there were no episodes of maternal hypoglycemia while the patients were treated with the GlucoStabilizer software program. There were also no significant differences in neonatal outcomes (Table 2).

Comment

Principal findings

This study demonstrates the safety and effectiveness of a computerized insulin dosing program in the intrapartum treatment of women with diabetes mellitus in pregnancy. In women with diabetes mellitus that requires an insulin infusion in labor, intrapartum insulin dosing with the GlucoStabilizer software program led to a 9-fold increased rate of glucose measurements in target range (70−100 mg/dL; 3.9−5.5 mmol/L) at the time of delivery compared with standard insulin dosing charts. This study is the first to demonstrate that the use of a software-guided intravenous insulin dosing program in obstetrics can improve intrapartum glycemia in women with both pregestational and gestational diabetes mellitus that is treated with insulin infusions without increasing maternal hypoglycemia.

Clinical implications

With the rising prevalence of obesity coinciding with diabetes mellitus, currently it is estimated that diabetes mellitus affects approximately 8% of all pregnancies.[13] Maternal hyperglycemia affects all stages of embryonic and fetal development and is associated with significant maternal and neonatal morbidities.[14,15] Previous studies have shown that maternal hyperglycemia before delivery is predictive of neonatal hypoglycemia and its associated morbidities.[11,12] Symptomatic neonatal hypoglycemia can result in brain injury that can be detected by magnetic resonance imaging and has been associated with long-term neurodevelopmental delays.[16-19] A study by Curet et al[20] demonstrated that the intrapartum plasma glucose concentration had a stronger association with decreased neonatal hypoglycemia than antepartum plasma glucose levels. Studies have also demonstrated that maintaining maternal euglycemia in proximity to delivery also decreases the risk of neonatal hypoglycemia.[12,21] In a study by Njenga et al,[22] intravenous insulin infusion dosing during labor prevented neonatal hypoglycemia with a mean blood glucose of 94±40 mg/dL (5.2±2.2 mmol/L) before delivery and 85±33 mg/dL (4.7±1.8 mmol/L) just before labor. Based on such observations, both the American College of Endocrinology and American College of Obstetricians and Gynecologists recommend maintaining maternal blood glucose concentration at <110 mg/dL (6.1 mmol/L) during labor.[15,23]

Methods for maintaining glycemic targets include the close monitoring of capillary blood glucose concentration with increased monitoring frequency in active labor and the initiation of an insulin infusion with persistently elevated glucose values.[14,24] Because maintaining optimal glycemic target values can be complex, strategies to reach these goals should be evaluated, and software-guided insulin dosing is a novel way to achieve optimal intrapartum glycemia. The superiority of the GlucoStabilizer software program, compared with standard insulin dosing charts, is founded on its ability to individualize insulin doses based on an individual's response to treatment and not just based on glucose measurements. This is a novel application to obstetrics that has been well-validated in critical care settings. This program calculates the insulin dose with the use of a validated formula: (blood glucose−60) × insulin sensitivity factor=insulin dose/hr. This formula was derived originally to determine the basal insulin requirements delivered via insulin pump and then validated in critical care settings in individuals with varying degrees of insulin resistance, with the use of a variable insulin sensitivity factor.[25,26] The insulin sensitivity factor is started at 0.02 and is adjusted progressively until the formula calculates insulin doses that bring glucose concentrations to target range. With the capacity to adjust the insulin sensitivity factor, this formula can be applied to patients with varying degrees of insulin resistance and response to stress in labor, which makes it ideal for intrapartum management of

TABLE 2
Comparison of outcomes for standard insulin infusion vs GlucoStabilizer software program (Indiana University Health Inc, Indianapolis, IN)

Variable	Standard insulin infusion (n=22)	GlucoStabilizer software program (n=11)	*P* value[a]
Patients with glucose within target at delivery,[b] n (%)	2 (9.1)	9 (81.8)	.0001
Mean glucose value on insulin infusion, mg/dL[c]	121.7±5.9	102.9±5.3	.02
Maternal hypoglycemia, n (%)	1 (4.3)	0	.99
Mean glucose value before infusion, mg/dL[c]	131.9±10.1	122.6±8.8	.5
Neonatal intensive care unit admission for hypoglycemia, n (%)	5 (22.7)	2 (18.2)	.99
Neonatal glucose concentration immediately after delivery, mg/dL[c]	62.0±20.1	55.2±18.6	.35
Neonatal respiratory distress syndrome, n (%)	6 (27.3)	3 (27.3)	.99
Neonatal hyperbilirubinemia requiring phototherapy, n (%)	10 (45.5)	7 (63.6)	.46

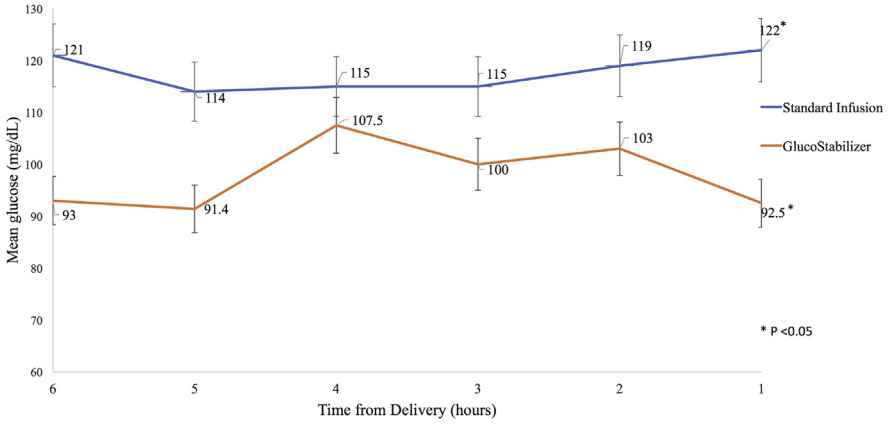
[a] Fisher's Exact test for categoric variables; 2 independent samples *t*-test for continuous variables; [b] Target glucose defined as 70–100 mg/dL; [c] Values are expressed as mean±standard deviation.

Dinglas et al. GlucoStabilizer insulin dosing and intrapartum glycemic management. Am J Obstet Gynecol 2018.

both pregestational and gestational diabetes mellitus (Figure 2).

The added benefit of using a software-guided insulin dosing program is its safety profile. The Institute for Safe Medical Practices lists insulin as 1 of 5 high alert medications, based on the Institute for Safe Medical Practices study[27] of avoidable medication errors. The GlucoStabilizer software program reduces risk by calculating intravenous insulin doses automatically and alerting nurses with audible and visual alarms to support timely dosing adjustments.

FIGURE 3
Comparison of mean glucose values 6 hours before delivery: standard insulin infusion vs GlucoStabilizer (Indiana University Health Inc, Indianapolis, IN) software program



The effectiveness of the GlucoStabilizer software program is shown in reaching target glucose values before delivery compared with standard insulin dosing chart-based protocol.

Dinglas et al. GlucoStabilizer insulin dosing and intrapartum glycemic management. Am J Obstet Gynecol 2018.

Strengths and weaknesses

One of the strengths of our study is that we include women with pregestational (type 1 diabetes mellitus and type 2 diabetes mellitus) and gestational diabetes mellitus, which allows for utility of this application in women with all degrees of insulin sensitivity. This is attributed to the ability of the GlucoStabilizer software program to adjust insulin dosing based on an individual's response to treatment. Also, our cohort of women who require insulin treatment in labor would most benefit from optimization of maternal glycemic treatment, because they represent a population at greatest risk for maternal hyperglycemia with subsequent neonatal hypoglycemia. We demonstrate that our interventions show improvement in intrapartum glycemia in this most vulnerable population. Although using a standard insulin dosing protocol is commonplace in intrapartum management, its utility has not been well-validated resulting in variations in management among different institutions. Our study provides proof that the use of a software-guided insulin dosing program can be replicated easily in other institutions, where similar software tools are likely being used in their critical care settings.

A major limitation of study is our small sample size, which likely accounts for our inability to demonstrate improvement in neonatal outcome. However, our study was adequately powered for our primary outcome.

Conclusions

Intrapartum glycemic management is important for both the mother and fetus because labor can challenge maternal requirements for both glucose and insulin. The achievement of strictly defined glycemic targets can help reduce maternal and neonatal morbidity. Based on our findings, we demonstrate the benefit of software-guided insulin infusion dosing in obstetrics to optimize intrapartum glycemic treatment in

women with both pregestational and gestational diabetes mellitus.

Research implications

We used the percentage of women who achieved glucose values in target range as our primary outcome to establish the superiority of the GlucoStabilizer software program over standard insulin dosing chart—based protocol in intrapartum management. Prospective randomized multicentered studies are needed to determine whether such improvement in maternal glycemia in labor leads directly to decreased neonatal hypoglycemia and other potential obstetric and neonatal benefits. ■

Acknowledgments

The authors acknowledge the following individuals who have supported this research: Emily Talucci, MD, Jay Davis, MD, Wendy Kinzler, MD, Jane Wendel, RN, and the staff of the NYU Winthrop Diabetes and Obesity Institute.

References

1. Peng TY, Ehrlich SF, Crites Y, et al. Trends and racial and ethnic disparities in the prevalence of pre-gestational type 1 and type 2 diabetes in Northern California: 1996-2014. Am J Obstet Gynecol 2017;216:177.e1-8.

2. Miremberg H, Ben-Ari T, Betzer T, et al. The impact of a daily smartphone-based feedback system among women with gestational diabetes on compliance, glycemic control, satisfaction, and pregnancy outcome: a randomized controlled trial. Am J Obstet Gynecol 2018;218:453.e1-7.

3. Romero R, Erez O, Hüttemann M, et al. Metformin, the aspirin of the 21st century: its role in gestational diabetes mellitus, prevention of preeclampsia and cancer, and the promotion of longevity. Am J Obstet Gynecol 2017;217:282-302.

4. Wang C, Wei Y, Zhang X, et al. A randomized clinical trial of exercise during pregnancy to prevent gestational diabetes mellitus and improve pregnancy outcome in overweight and obese pregnant women. Am J Obstet Gynecol 2017;216:340-51.

5. Martinez NG, Niznik CM, Yee LM. Optimizing postpartum care for the patient with gestational diabetes mellitus. Am J Obstet Gynecol 2017;217:314-21.

6. Moore TR, Hauguel-DeMouzon S, Catalano P. Diabetes in pregnancy: intrapartum glycemic management. In: Creasy RK, Resnik R, Iams JD, et al, eds. Creasy & Resnick's maternal fetal medicine: principles and practice, 7th ed. Philadelphia: Saunders/Elselvier; 2014. p.1020.

7. Juneja R, Roudebush C, Kumar N, et al. Utilization of a computerized intravenous insulin infusion program to control blood glucose in the intensive care unit. Diabetes Technol Ther 2007;9:232-40.

8. Juneja R, Roudebush C, Nasraway SA, et al. Computerized intensive insulin dosing can mitigate hypoglycemia and achieve tighter glycemic control when glucose measurement is performed frequently and on time. Crit Care 2009;13:R163.

9. Juneja R, Golas A, Carroll J, et al. Safety and effectiveness of a computerized subcutaneous insulin program to treat inpatient hyperglycemia. J Diabetes Sci Technol 2009;2:384-91.

10. Harris S, Nisly SA, Aykroyd L, et al. Use of a subcutaneous insulin computerized GlucoStabilizer™ program on glycemic control in the critical care setting: a retrospective data analysis. Adv Diabetes Metab 2013;1:29-35.

11. Kline GA, Edwards A. Antepartum and intrapartum insulin management of type 1 and type 2 diabetic women: impact on clinically significant neonatal hypoglycemia. Diabetes Res Clin Pract 2007;77:223-30.

12. Iafusco D, Stoppoloni F, Salvia G, et al. Use of real time continuous glucose monitoring and intravenous insulin in type 1 diabetic mothers to prevent respiratory distress and hypoglycaemia in infants. BMC Pregnancy Childbirth 2008;8:23.

13. Centers for Disease Control and Prevention. National Diabetes Statistics Report, 2017. Atlanta (GA): Centers for Disease Control and Prevention, US Department of Health and Human Services; 2017.

14. American College of Obstetricians and Gynecologists. ACOG Practice Bulletin no. 190: gestational diabetes mellitus. Washington, DC: American College of Obstetricians and Gynecologists; 2018.

15. American College of Obstetricians and Gynecologists. ACOG Practice Bulletin no. 60: pregestational diabetes mellitus. Washington, DC: American College of Obstetricians and Gynecologists; 2005.

16. Burns CM, Rutherford MA, Boardman JP, Cowan FM. Patterns of cerebral injury and neurodevelopmental outcomes after symptomatic neonatal hypoglycemia. Pediatrics 2008;122:65.

17. Am EW, Widjaja E, Blaser SI, Macgregor DL, Satodia P, Moore AM. Occipital lobe injury and cortical visual outcomes after neonatal hypoglycemia. Pediatrics 2008;122:507.

18. McKinlay CJD, Alsweiler JM, Anstice NS, et al. Association of Neonatal Glycemia with Neurodevelopmental Outcomes at 4.5 Years. JAMA Pediatr 2017;171:972.

19. Kaiser JR, Bai S, Gibson N, et al. Association between transient newborn hypoglycemia and fourth-grade achievement test proficiency: a population-based study. JAMA Pediatr 2015;169:913-21.

20. Curet LB, Izquierdo LA, Gilson GJ, Schneider JM, Perelman R, Converse J. Relative effects of antepartum and intrapartum maternal blood glucose levels on incidence of neonatal hypoglycemia. J Perinatol 1997;17:113-5.

21. Roman A, Moreno S, Lynch T, Berghella V. Intrapartum glycemic control and risk of neonatal hypoglycemia. Am J Obstet Gynecol 2017;216(suppl):S310-1.

22. Njenga E, Lind T, Taylor R. Five-year audit of peripartum blood glucose control in type 1 diabetic patients. Diabet Med 1992;9:567-70.

23. Garber AJ, Moghissi ES, Bransome ED Jr, et al. American College of Endocrinology position statement on inpatient diabetes and metabolic control. Endocr Pract 2004;10(suppl 2):4-9.

24. Caplan RH, Pagliara AS, Beguin EA, Smiley CA, Bina-Frymark M, Goettl KA. Constant intravenous insulin infusion during labor and delivery in diabetes mellitus. Diabetes Care 1982;5:6-10.

25. White NH, Skor D, Santiago JV. Practical closed-loop insulin delivery: a system for the maintenance of overnight euglycemia and calculation of basal insulin requirements in insulin-dependent diabetics. Ann Intern Med 1982;97:201-13.

26. Davidson PC, Steed RD, Bode BW. Glucommander: a computer-directed intravenous insulin system shown to be safe, simple and effective in120,618 h of operation. Diabetes Care 2005;28:2418-23.

27. Cohen RR, Smetzer JL, Tuohy NR, Kilo CM. High-alert medications: safeguarding against errors. In: Cohen MR, ed. Medical errors, 2nd ed. Washington DC: American Pharmacists Association; 2007:317-412.

Author and article information

From New York University Winthrop Hospital, Mineola, New York, NY.

Received March 19, 2018; revised April 30, 2018; accepted May 2, 2018.

The authors report no conflict of interest.

Presented in abstract form at the 38th Annual Meeting of the Society for Maternal Fetal Medicine; Dallas, TX, January 31—February 3, 2018.

Corresponding author: Hye J. Heo, MD, CDE. hye.heo@nyulangone.org