Original Research

Semiautonomous Treatment Algorithm for the Management of Severe Hypertension in Pregnancy

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OBJECTIVE: To evaluate whether implementation of a semiautonomous treatment algorithm was associated with improved compliance with American College of Obstetricians and Gynecologists guidelines for rapid administration of antihypertensive therapy in the setting of sustained severe hypertension.

METHODS: This was a single-center retrospective cohort study of admitted pregnant and postpartum patients treated for severe hypertension between January 2017 and March 2020. The semiautonomous treatment algorithm, which included vital sign monitoring, blood pressure thresholds for diagnosis of severe hypertension, and automated order sets for recommended first-line antihypertensive therapy were implemented between May 2018 and March 2019. The primary outcomes were the administration of antihypertensive therapy within 15, 30 and 60 minutes of diagnosis of severe hypertension. Comparisons were made between the preimplementation, during implementation, and postimplementation groups using χ^2. Analysis was limited to the first episode of severe hypertension treated. Statistical significance was defined as $P<.05$.

RESULTS: In total, there were 959 obstetric patients treated for severe hypertension, with 373 (38.9%) treated preimplementation, 334 (34.8%) during implementation, and 252 (26.2%) after implementation. Treatment of severe hypertension within 15 minutes was 36.5% preimplementation, 45.8% during implementation, and 55.6% postimplementation ($P=.001$). Treatment within 30 minutes was 65.9% in the preimplementation group, 77.8% during implementation, and 79.0% in the postimplementation group ($P=.004$). There was no difference in percentage of patients treated within 60 minutes (86.3% before, 87.7% during and 92.9% after implementation, $P=.12$).

CONCLUSION: Implementation of a semiautonomous treatment algorithm for severe hypertension was associated with a higher percentage of pregnant and postpartum patients receiving the first dose of antihypertensive therapy within 15 and 30 minutes. Implementation of similar algorithms for this and other obstetric indications may decrease time to appropriate therapy and help improve care equity.

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Hypertensive disorders complicate between 2% and 7% of pregnancies in the United States and are[1,2] associated with serious obstetric complications, which include fetal growth restriction, placental abruption, stillbirth, cesarean delivery, postpartum hemorrhage, seizure, and stroke.[3–6] In addition, hypertensive disorders are one of the leading causes of maternal mortality.[7] Early intervention with antihypertensive agents and magnesium sulfate for verified sustained severe-range blood pressures reduces the rate of eclampsia and severe maternal morbidity.[8–10] Therefore, the American College of Obstetricians and Gynecologists

(ACOG) recommends that acute severe hypertension be treated as soon as possible, with no more than 30–60 minutes of delay.[11] Despite these recommendations, recent reviews demonstrate poor compliance with the rapid administration of antihypertensive therapy.[12] This may be due to multiple factors, such as lack of intravenous access, inadequate health care practitioner or nursing availability, and implicit racial biases.[13]

Clinical care pathways that incorporate clinical data surveillance and standardized treatment algorithms have been used in various areas of medical practice for more than 20 years.[14] These standardized pathways may decrease delays and errors in communication. Electronic medical records (EMRs) allow for the integration of semiautonomous algorithms that further reduce treatment delays and improve health care quality.[15] These semiautonomous algorithms have been effectively used in the treatment of conditions, such as myocardial infarction, heart failure, acute stroke, and asthma.[16–18] However, use of semiautomated treatment algorithms in obstetrics is limited.

Given the need for rapid clinical decision-making and administration of treatment in the management of severe hypertension in pregnancy, we hypothesized that a semiautonomous treatment algorithm would be associated with decreased time to treatment of severe hypertension in obstetric inpatient settings. Therefore, we designed and implemented such a system in our institution for the initial treatment of severe hypertension in obstetric patients, based on ACOG recommendations. The primary objective of this study was to evaluate whether there were differences in time to initiation of the treatment of severe hypertension in pregnancy and postpartum, before and after implementation of a semiautonomous treatment algorithm.

METHODS

This was a retrospective cohort study of pregnant and postpartum patients treated for severe hypertension at a tertiary care academic hospital from January 2017 until March 2020. Severe hypertension was defined as systolic blood pressure 160 mm Hg or higher or diastolic blood pressure 110 mm Hg or higher. All patients with pregnancies beyond 20 0/7 weeks of gestation through 6 weeks postpartum were eligible for inclusion. Patients were excluded if the blood pressure measurements were deemed to be inaccurate based on nursing documentation. This study was approved by the Loma Linda University institutional review board (IRB# 5190120)

Between May 2018 and March 2019, a semiautonomous treatment algorithm was integrated into the EMR for the administration of the initial antihypertensive therapy based on ACOG guidelines. The

inclusion criteria for semiautonomous algorithm monitoring and treatment were predetermined based on patient age, pregnancy status, and the admission location entered into the EMR at registration (Box 1). The algorithm included monitoring and analysis of clinical information such as vital signs, intravenous access, and prior medical history. The clinical information entered into the EMR was validated by nursing staff at the patient's bedside. Blood pressure measurements were taken in the presence of the nurse to ensure proper cuff placement and patient positioning. Based on information entered into the EMR, the algorithm identified patients with severe hypertension when two consecutive blood pressure measurements of at least 15 minutes apart exceed 160 mm Hg systolic or 110 mm Hg diastolic. The semiautonomous treatment algorithm then provided immediate management recommendations and medication administration orders in the EMR for a first-line antihypertensive therapy that included appropriate dosing directly to the nursing staff. The antihypertensive agent recommended by the semiautonomous treatment algorithm considers contraindications to specific classes of medications, as well as other clinical information to provide an additional layer of safety. For example, the semiautonomous treatment algorithm will default to hydralazine or nifedipine in patients with asthma or bradycardia in whom labetalol is contraindicated (Fig. 1). The treatment episode concludes when blood pressures are less than 160/110 for at least 120 minutes. We chose 120 minutes as the minimum duration of each treatment episode to ensure adequate response to therapy and ongoing close blood pressure monitoring. A subsequent new treatment episode was triggered if the patient's blood pressure again exceeded the severe range limit outside of the initial treatment interval. Health care practitioner input was not required for semiautonomous treatment algorithm-initiated treatments. Nursing staff were instructed to notify the on-call practitioner when antihypertensive medications were being administered and to seek further instructions after initial treatment.

Box 1. Semiautonomous Treatment Algorithm Inclusion Criteria

Inclusion criteria (must meet all of the following):
- Age 60 y or younger
- Pregnant or within 6 wk postpartum
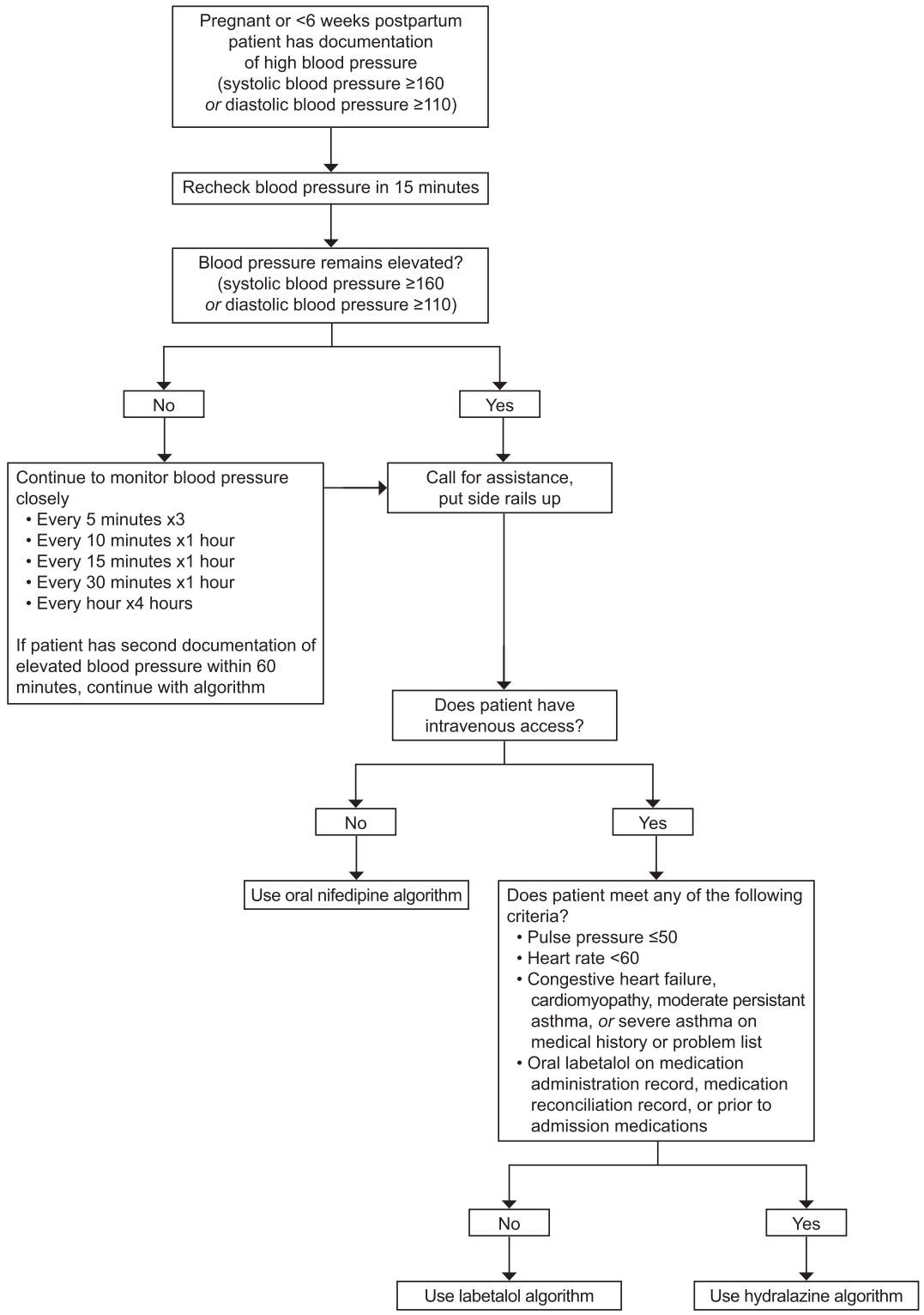- Standing orders are available for initial dose of antihypertensive medications (in maternity units)

Fig. 1. Semiautonomous treatment algorithm integrated into the electronic medical record system for the treatment of severe hypertension in pregnancy.

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The cohort was divided into three groups relative to implementation of the semiautonomous treatment algorithm. The preimplementation group included patients hospitalized between January 2017 and April 2018, during which time there was no standardized algorithm for treating severe hypertension. The during implementation group included patients hospitalized between May 2018 and March 2019. During this time period, in addition to live implementation of the semiautonomous treatment algorithm in the EMR, the authors provided nursing and physician education and compliance review to improve adherence to the semiautonomous treatment algorithm. The postimplementation group included patients hospitalized between April 2019 and March 2020 after complete adoption of the semiautonomous treatment algorithm. Separating these three groups for comparison allowed us to evaluate the effect of the semiautonomous treatment algorithm on time to initiation of treatment for severe hypertension while minimizing the potential Hawthorne effect during the implementation phase. Only the first treatment episode for each participant was included in the analysis.

Medical records were abstracted for basic demographic information and clinical outcomes. Race and ethnicity were self-reported at the time of admission or during prenatal visit and categorized to non-Hispanic White, non-Hispanic Black, Hispanic, Asian, more than one category, or none of the above. Baseline demographic information was compared between groups. Normally distributed variables were compared using analysis of variance test. If not normally distributed, the Kruskal-Wallis test was used. Categorical variables were compared between the three groups using χ^2.

The primary outcomes of interest were the percentage of patients receiving the recommended antihypertensive medication within 15, 30, and 60 minutes of diagnosis of severe hypertension. Preimplementation, during implementation, and postimplementation groups were compared using χ^2. Statistical significance was defined as $P<.05$. Statistical analyses were performed using Stata 14 (College Station, Texas).

RESULTS

Between January 2017 and March 2020, there were 1,094 pregnant or postpartum patients identified with severe hypertension. Of these, 131 patients were excluded owing to documented inappropriate blood pressure measurement. In most cases of a documented inappropriate measurement, the blood pressure cuff was not properly placed, or the patient was not positioned correctly (eg, arms bent during

second stage of labor). An additional four patients were excluded for having a gestational age of less than 20 weeks. The final cohort for analysis included 959 patients treated for severe hypertension. Among them, 373 (38.9%) were treated before the semiautonomous treatment algorithm implementation, 334 (34.8%) were treated during implementation, and 252 (26.2%) were treated after implementation (Fig. 2).

There were no differences in maternal age, parity, body mass index, gestational age, self-reported race, or chronic hypertension before and after the semiautonomous treatment algorithm implementation. The rate of patients with Medicaid insurance increased from 15.0% preimplementation to 27.5% during implementation and 41.7% postimplementation ($P<.001$) (Table 1), consistent with known payer mix changes based on hospital contracting decisions.

The medication used as the first-line antihypertensive agent changed over time ($P=.027$). The proportion of oral nifedipine use increased from 16.6% preimplementation to 21.8% during implementation and 26.6% after implementation. There was a corresponding decrease in proportion of intravenous labetalol use from 66.8% preimplementation to 59.0% during implementation, and 57.5% at the postimplementation phase (Table 2).

Treatment of severe hypertension within 15 minutes was 36.5% at preimplementation, 45.8% during implementation and 55.7% at postimplementation ($P=.001$). Treatment within 30 minutes was 65.9% at preimplementation, 77.8% during implementation and 79.0% at postimplementation ($P=.004$). There was no difference in percentage of patients treated within 60 minutes between the preimplementation, during implementation, and postimplementation groups (86.3%, 87.7%, and 92.9%, $P=.12$) (Table 2).

DISCUSSION

This study demonstrates an association between the implementation of a semiautonomous treatment algorithm and decreased time to antihypertensive therapy for severe hypertension in the acute obstetric care setting. Over the course of implementation, we observed a 13% improvement in adherence to the ACOG guidelines for expeditious treatment of severe hypertension in pregnancy within 30 minutes. Furthermore, after implementation of the semiautonomous treatment algorithm, more than half of all patients were treated within 15 minutes, an improvement of nearly 20%. More importantly, these changes were sustained after the implementation phase.

The semiautonomous treatment algorithm allowed for consistent evidence-based management of
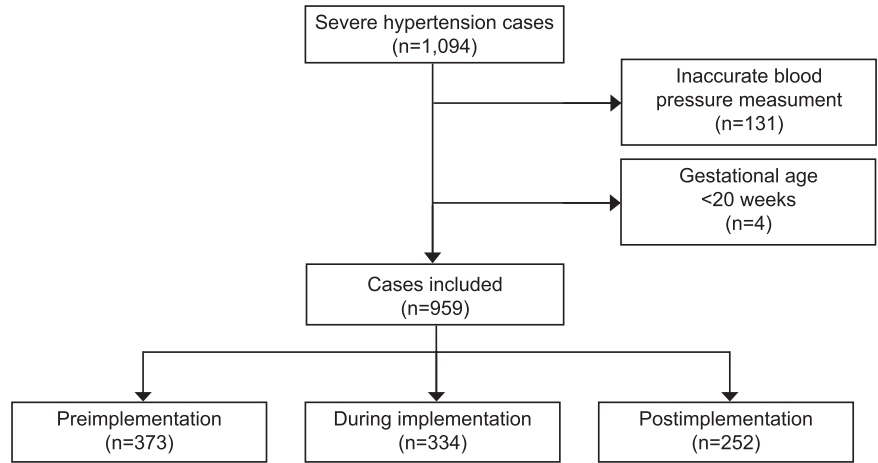
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        ┌──────────────────────────┐
        │  Severe hypertension cases│
        │        (n=1,094)          │
        └──────────────────────────┘
                   │                    ┌──────────────────────────┐
                   │───────────────────▶│   Inaccurate blood        │
                   │                    │ pressure measument        │
                   │                    │        (n=131)            │
                   │                    └──────────────────────────┘
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                   │───────────────────▶│   Gestational age         │
                   │                    │     <20 weeks             │
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        │     Cases included        │
        │        (n=959)            │
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 │Preimplementation│During implementation│Postimplementation│
 │   (n=373)    │ │   (n=334)    │ │   (n=252)    │
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Fig. 2. Cohort selection.

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one of the most common complications faced by obstetric health care practitioners. Notably, our institution's compliance with treatment of severe hypertension within 60 minutes was high even before implementing the semiautonomous treatment algorithm (86.3%). Although this may be unique to our institution, we were still able to improve on this metric by implementing the algorithm. Furthermore, time to treatment continues to improve in the post-implementation phase, which suggests that the improvement is sustained and independent of training related effects.

A recent publication on the barriers to timely treatment of severe hypertension in pregnancy noted an overall compliance rate of less than 50% for time to treatment under 60 minutes. This study identified differences in compliance with guidelines between day and night shifts, by race, and by other signs and symptoms of preeclampsia and onset of labor.[13] Hesitation in clinical decision-making may be rooted in the desire for thorough clinical evaluation. Yet, studies have demonstrated the benefits of early treatment of severe hypertension in pregnancy.[8,19] The semiautonomous treatment algorithm can eliminate many of the barriers identified by objectively monitoring each blood pressure measurement and can provide actionable nursing orders based on strict treatment guidelines, without bias, even in clinical settings with limited staffing.

The efficacy of a semiautonomous treatment algorithm is highly dependent on accurate real-time clinical information. To this end, close monitoring by skilled nursing staff is critical. The nursing staff must follow the semiautonomous treatment algorithm directives and validate each blood pressure measurement recorded in the EMR at the patient's bedside. With this safety check in place, we did not observe

any cases of inappropriately administered treatments or hypotensive episodes during the study period.

Treatment algorithms have seen limited use in other areas of obstetric management. A clinical pathway for labor management demonstrated a reduction in episiotomy rate,[20] and a treatment algorithm to improve recovery after cesarean delivery was associated with a reduction in hospital length of stay and cost.[21] Effective care pathways such as these can be integrated into the EMR system to enhance compliance and further improve clinical outcomes. Additionally, there are many other time-sensitive clinical scenarios in routine obstetric practice that might benefit from semiautonomous treatment algorithm implementation.

The semiautonomous treatment algorithm implemented in our study was limited to the initial management of severe hypertension. However, it can be expanded to follow the entire ACOG algorithm for the evaluation and management of hypertension in pregnancy. Such systems could allow for objective management of each patient who presents with hypertension in pregnancy with minimal input and oversight. Furthermore, as the trend toward integration of artificial intelligence in health care delivery continues, such systems can be integrated with artificial intelligence surveillance to adjust the medical recommendations based on individual clinical variables to truly achieve personalized health care delivery and minimize adverse outcomes. Future research should focus first on developing semiautonomous treatment algorithms for various clinical scenarios with testing of their clinical safety and efficacy. Once effectiveness is satisfactorily demonstrated, further investigation can focus on the integration of more fully automated decision support and treatment systems.

One major strength of our study is the consistency of health care delivery with the semiautonomous

Table 1. Demographic Information

Characteristic	Preimplementation	During Implementation	Postimplementation	P
n	373	334	252	
Maternal age (y)	30.9±6.3	30.9±6.5	31.6±6.1	.34
Parity	1 (0–8)	1 (0–8)	1 (0–7)	.59
BMI (kg/m^2)	37.4±9.6	36.9±9.5	37.8±8.4	.52
Gestational age at treatment (wk)	38 (23–41)	37 (20–41)	37 (21–43)	.77
Gestational age at delivery (wk)	37 (23–42)	37 (20–41)	37 (21–43)	.70
Race*				
White	86 (23.0)	82 (24.6)	60 (24.1)	.53
Black	46 (12.3)	61 (18.3)	37 (14.7)	
Hispanic	185 (49.7)	139 (41.6)	115 (45.6)	
Asian	17 (4.6)	14 (4.2)	11 (4.4)	
None of the above or mixed	39 (10.4)	38 (11.4)	29 (11.5)	
Medicaid	56 (15.0)	92 (27.5)	105 (41.7)	<.001
Chronic hypertension	83 (22.3)	93 (27.8)	65 (25.8)	.22

BMI, body mass index.
Data are mean±SD, median (range), or n (%) unless otherwise specified.
* Self-reported race or ethnicity.

treatment algorithm. The findings presented were the results of semiautonomous treatment algorithm implementation in a large and diverse obstetric practice, with 20 obstetric attending physicians overseeing more than 30 resident physicians. The consistency of health care delivery was demonstrated by significant improvement in treatment time, despite the diversity in attending physicians. Additionally, such systems can be universally adopted by any health care institution with EMR capability. Therefore, we expect high reproducibility of our results at other institutions. Furthermore, the prolonged study duration allowed us to assess how semiautonomous treatment algorithms affect clinical management while accounting for potential Hawthorne Effect during the implementation phase.

This study has limitations. Owing to the policy of universal implementation, we were not able to disentangle any potential effect from peer-to-peer education and other in-service training on timely treatment of severe hypertension from the effect of the semiautonomous treatment algorithm itself. However, we did note that even after full implementation of the semiautonomous treatment algorithm, the compliance rate for timely treatment of severe hypertension did not decrease. Additionally, owing to a relatively long study period, there may be other practice changes over time that we cannot account for, in addition to the implementation of the semiautonomous treatment algorithm. Although the study demonstrated an association between implementation of the algorithm and a reduction in the time to administration of antihypertensive therapy, it is unknown whether it improves maternal and neonatal outcomes. Future studies are needed to determine the optimal timing of treatment in cases of severe hypertension in terms of maternal and perinatal risk reduction.

Table 2. Treatment Characteristics

Characteristic	Preimplementation (n=373)	During Implementation (n=334)	Postimplementation (n=252)	P
Treatment medication				
IV hydralazine	62 (16.6)	64v (19.2)	40 (15.9)	.027
IV labetalol	249 (66.8)	197 (59.0)	145 (57.5)	
Oral nifedipine	62 (16.6)	73 (21.9)	67 (26.6)	
Treatment under 60 min	322 (86.3)	293 (87.7)	234 (92.9)	.12
Treatment under 30 min	246 (65.9)	260 (77.8)	199 (79.0)	.004
Treatment under 15 min	136 (36.5)	153 (45.8)	140 (55.6)	.001

Data are n (%) unless otherwise specified.
IV, intravenous.

Despite the limitations, our study demonstrated the potential efficacy of a semiautonomous treatment algorithm system to improve adherence to guidelines in the treatment of severe hypertension in pregnancy and postpartum. In the United States, the obstetric population is becoming older and more obese.[22–24] These two trends alone predict a continuing rise in the rates of hypertensive disorders in pregnancy. Treatment of severe hypertension in pregnancy and its sequelae will occupy a growing portion of health care resources. Integration of semiautonomous treatment algorithms similar to ours into routine obstetric practices could help reduce the health care burden and improve clinical outcomes especially in areas with limited health care resources.

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