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Identifying Hypertension in Pregnancy using Electronic Medical Records: The importance of Blood Pressure Values

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Abstract

Objective: To incorporate blood pressure (BP), diagnoses codes, and medication fills from electronic medical records (EMR) to identify pregnant women with hypertension.

Study design: a retrospective cohort study of singleton pregnancies at three US integrated health delivery systems during 2005–2014.

Main outcome measures: Women were considered hypertensive if they had any of the following: (1) ≥2 high BPs (≥ 140/90 mmHg) within 30 days during pregnancy (High BP); (2) an antihypertensive medication fill in the 120 days before pregnancy and a hypertension diagnosis from 1 year prior to pregnancy through 20 weeks gestation (Treated Chronic Hypertension); or (3) a high BP, a hypertension diagnosis, and a prescription fill within 7 days during pregnancy (Rapid Treatment). We described characteristics of these pregnancies and conducted medical record review to understand hypertension presence and severity.

Results: Of 566,624 pregnancies, 27,049 (4.8%) met our hypertension case definition: 24,140 (89.2%) with High BP, 5,409 (20.0%) with Treated Chronic Hypertension, and 5,363 (19.8%) with Rapid Treatment (not mutually exclusive). Of hypertensive pregnancies, 19,298 (71.3%) received

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a diagnosis, 9,762 (36.1%) received treatment and 11,226 (41.5%) had a BP ≥ 160/110. In a random sample (n=55) of the 7,559 pregnancies meeting the High BP criterion with no hypertension diagnosis, clinical statements about hypertension were found in medical records for 58% of them.

Conclusion: Incorporating EMR BP identified many pregnant women with hypertension who would have been missed by using diagnosis codes alone. Future studies should seek to incorporate BP to study treatment and outcomes of hypertension in pregnancy.

Introduction

Hypertensive disorders, including preeclampsia, chronic and gestational hypertension, affects nearly 300,000 (6–8%) pregnancies annually in the US, increasing risks of adverse outcomes including maternal and perinatal death and medically indicated preterm birth.[1–7] The guideline from American College of Obstetricians and Gynecologists (ACOG), which informs U.S. clinical practice, defines hypertension in pregnancy as a systolic blood pressure (BP) ≥ 140 mm Hg, and/or a diastolic BP ≥90 mm Hg, typically on 2 occasions at least 4 hours apart.[8] Administrative claims data have been used to evaluate prevalence[2,9–13] and outcomes[14] of hypertension during pregnancy. In contrast to the ACOG clinical definition, such studies define hypertension in pregnancy based on diagnosis codes,[2,9–14] often relying solely on codes recorded at the delivery hospitalization.[2,9–11,13,14] However, this approach has relatively low sensitivity:in non-pregnant adult populations, defining hypertension based on 2 or more diagnosis codes within 3 years only achieved 73% sensitivity and 95% specificity, and additionally requiring pharmacy claims improved specificity but decreased sensitivity.[15,16] Hence, studies based on claims data may substantially underestimate the true burden of hypertensive disease in pregnancy.

Increasingly available large scale electronic medical record (EMR) data containing richer clinical data than claims data provides opportunities for improved ascertainment of various diseases[17,18] including hypertension.[19] A hypertension case definition based on a combination of diagnosis codes, medication fills and BP has been used in studies of non-pregnant populations.[20–22] We aimed to identify hypertension during pregnancy using an approach that integrates BP with diagnoses and antihypertensive medication fills. We also sought to better understand discrepancies in cases identified by this approach versus other methods.

Methods

This study used data from a cohort study of singleton pregnancies within three healthcare systems: Kaiser Permanente Northern California (KPNC), Southern California (KPSC) and Washington (KPWA), who together provide medical coverage and care to over 10 million members. The goal of the parent study was to examine the impact of antihypertensive treatments on maternal and neonatal outcomes within singleton pregnancies. The current study describes the approach used to identify the study cohort. Research activities were approved by the institutional review boards at each Kaiser Permanente region and by state institutional review boards (governing the use of birth certificate data).

Study Population

We included singleton live or stillbirth pregnancies among women between ages 15 and 49 years during 2007–2014 at KPSC or KPWA, and 2005–2014 at KPNC (based on the time periods when EMR BPs became available). Pregnancies were identified via hospital pregnancy registries supplemented with diagnosis and procedure codes. Gestational age was ascertained primarily from clinical data in the EMR such as the estimated due date (EDD), which is based on results of first trimester ultrasound or the date of last menstrual period if the former was missing. We then estimated the start of pregnancy as the EDD minus 280 days. To ensure sufficient data for ascertaining hypertension, we restricted to pregnancies that had: a non-missing gestational age at delivery, continuous enrollment in the health plan from no later than 16 weeks gestation through delivery, and at least 1 recorded BP prior to 20 weeks gestation. The parent study made several exclusions to reduce confounding in studying hypertension treatment effect on birth outcomes, including: multiple gestations, certain rare conditions or exposure to teratogenic medications or medications indicative of severe maternal conditions (see Appendix 1).

Data source

All three health systems maintain a Virtual Data Warehouse (VDW) with common variables and definitions to facilitate data sharing and harmonization across systems.[24] From the VDW, we extracted women's enrollment information, BP, height, weight, diagnosis and procedure codes from health care encounters, and outpatient pharmacy fills. For women with multiple BPs recorded on a single day, the highest systolic and diastolic BP were used. Women's EMR were linked to state birth certificates to supplement information on maternal race/ethnicity, education, tobacco use, infant sex and parity (see Appendix 1).

Hypertension case definition

Because the parent study aimed to study pregnancies that may be candidates for oral antihypertensive treatment, we focused on hypertension that emerged by 35 weeks 6 days gestation so that there would be an opportunity for the mother to receive treatment and for the treatment to have an effect. We operationalized the ACOG definition of hypertension as 2 BPs ≥140/90 mm Hg recorded on separate days within 30 days from the start of the pregnancy through 35 weeks 6 days gestation ("High BP" criterion).[8] We then created 2 other criteria to identify women who were hypertensive but might not have repeated high BPs recorded in the EMR due to effective treatment. These were women: 1) with "Treated chronic hypertension" (defined as ≥1 fills of an antihypertensive medication in the 120 days before pregnancy plus a hypertension diagnosis code within 1 year prior to pregnancy through 20 weeks gestation); and 2) who received "Rapid Treatment" (defined as a BP of 140/90 or higher from start of the pregnancy through 35 weeks 6 days accompanied by 1 hypertension diagnosis plus 1 antihypertensive medication fill within 7 days of the high BP). Pregnancies could meet multiple criteria.

Some prior studies have defined hypertension based on outpatient BP alone, as inpatient BP may be influenced by acute illness.[20,25] Given the short time window to identify and treat hypertension in pregnancy, the ACOG guideline does not require using only outpatient BP.[8] Thus, our primary analyses did not distinguish BP by clinical setting.

Indicators and severity of hypertension

Among pregnancies identified as hypertensive by 35 weeks 6 days gestation, we then used EMR data collected throughout the pregnancy to examine various clinical characteristics that could be indicators for the presence and severity of hypertension. We first examined receipt of a hypertension diagnosis code in 2 ways: (1) *during pregnancy* —having 1 hypertension diagnosis code recorded from the start of pregnancy through delivery, or 1 inpatient diagnosis of preeclampsia or eclampsia[26] from 20 weeks gestation through delivery; and (2) *at the delivery hospitalization*— having 1 inpatient diagnosis code for hypertension, preeclampsia or eclampsia from three days prior to the delivery date through delivery date. We defined BP ≥140/90 mm Hg as high BP and BP≥160/110 mm Hg as severe high BP.[8] We calculated the proportion of women with at least 1 high BP and 1 severe high BP any time during pregnancy and from 20 weeks gestation to delivery. Lastly, we examined receipt of treatment, defined as filling ≥1 outpatient prescriptions of antihypertensive medications during pregnancy.

Medical record review

To better understand discrepancies in hypertensive cases according to our definition compared to cases according to other approaches, we reviewed medical records for a sample of pregnancies in three groups: (1) among women with multiple hypertension diagnosis codes, those who did not meet our hypertension case definition (Set A); (2) among women meeting our High BP criterion, those without hypertension diagnosis (Set B); and (3) among women filling antihypertensive medications, those did not meet our hypertension case definition (Set C). Because in our settings, labetalol and methyldopa are rarely used for other indications, we evaluated users of these 2 medications separately. Across all health systems, we selected random samples and reviewed 45–55 charts from each group. We searched medical records, including clinical notes, for evidence of high BP and antihypertensive prescriptions. For Set B, we also searched for recorded statements about hypertension in the clinical notes (e.g., mentions of “hypertension”, “white coat hypertension”, or “labile” or “elevated blood pressure”). Medical record review was conducted by trained abstractors at each site, who followed the same medical review manual of operations and met regularly as a group with study investigators to ensure consistency in interpreting and applying the manual.

Statistical analyses

We grouped pregnancies according to which criterion of our hypertension case definition they met. Pregnancies meeting multiple criteria were included in each group for which they met criteria. We calculated the proportion of total pregnancies meeting each criterion, examined overlap between these groups and described maternal demographic and clinical characteristics. Analyses were conducted using SAS version 9.4 (SAS Institute Inc., Cary, NC).

Results

We identified 566,624 eligible pregnancies, 30,669 were hypertensive according to our case definition. We further excluded 1,768 pregnancies with multiple gestations and 1852 with

rare conditions or certain teratogenic medication exposures, leaving a final analytic sample of 27,049 (Figure 1). In our cohort, 24,140 pregnancies (89.2%) were identified as hypertensive via the High BP criterion, and 75.5% of these were identified solely by this criterion (Figure 2). The Treated chronic Hypertension criterion identified 5,409 (20.0%) pregnancies as hypertensive and the Rapid Treatment criterion identified 5,363 (19.8%), and many pregnancies in these 2 groups also met the High BP criterion (52.9% and 87.9%, respectively).

In our hypertensive pregnancy cohort, the mean maternal age was 31.7 years, 63.6% of women were non-white, 7.7% had pre-existing diabetes, and only 18.7% had normal weight or were underweight prior to pregnancy (Table 1).

Clinical characteristics of the cohort overall and by subgroups are shown in Table 2. In our cohort, 71.3% received a hypertension diagnosis code recorded at any time during pregnancy with 33% having a hypertension diagnosis assigned prior to 20 weeks gestation. At delivery, 59.3% received a hypertension diagnosis code. This was largely driven by patterns seen in women identified by the High BP criterion, of whom 68.7% received a diagnosis code during pregnancy and 57.0% at delivery. Overall, 36.1% of hypertensive pregnancies were treated and 94.6% had at least 2 separate visits with recorded high BP. Severe high BP occurred to 41.5% of all pregnancies at some point during pregnancy and 20.8% between 20 weeks gestation and delivery. The proportion of experiencing a severe high BP varied across groups, with the highest proportion in the rapid treatment group.

Table 3 shows characteristics of 7,559 pregnancies (27.9% of our cohort) that met the High BP criterion without receiving a hypertension diagnosis code during pregnancy. Of these, only 7.7% were treated, 76.5% had at least 3 separate visits with recorded high BP, and 20.3% had at least 1 severe high BP.

Medical record reviews were conducted for a total of 150 pregnancies to elucidate discrepancies in cases identified by different methods (Table 4). Of pregnancies with multiple hypertension diagnosis code during pregnancy, 22.2% did not meet our case definition of hypertension (Set A). Of the 50 Set A cases reviewed, 14 (28.0%) had multiple high BPs and 8 (16.0%) filled antihypertensive medications during pregnancy. They, however, did not meet our definition either because prescriptions were filled outside of our facility or timing of fills or high BP were not in the specified time window. We also reviewed 55 pregnancies meeting our High BP criterion but did not have a hypertension diagnosis code (Set B) and found clinical notes with statements about hypertension, labile BP or white coat hypertension in 32 charts (58.1%). Set C cases were women who filled antihypertensive medications during pregnancy but did not meet our case definition, which accounted for 9.6% of those treated with labetalol or methyldopa and 46.4% of those treated with other medications. According to chart notes, 75.0% of the labetalol/methyldopa-treated group (n=15 out of 20 charts reviewed) was using the medication to treat hypertension, compared to 16.0% in the group treated with other medication (n=4 out of 25 chats reviewed).

In an ad-hoc analysis, we examined gestational ages at delivery. The mean (standard deviation) gestational age at delivery was 37.6 (3.0) weeks overall and ranged from 37.0 (3.3) in women identified by the Rapid Treatment criterion to 37.8 (2.9) weeks in women identified by the Treated Chronic Hypertension criterion. The mean gestational age at delivery was 37.5 (2.8) weeks among women with a hypertension diagnosis code at delivery and 37.7 (3.4) weeks among those without.

Discussion

In this large population-based study, we developed a comprehensive approach that integrated EMR BP with diagnosis codes and medication fills to identify pregnant women with hypertension. One of our key findings is that using BP identifies a large group of pregnant women (n=7,559, 28% of the cohort) who meet the clinical definition of hypertension according to EMR BP but would have been missed by using claims data alone. This finding further confirms the low sensitivity for claims-based hypertension definitions previously reported in non-pregnant populations.[15,16] One possible explanation for this finding could be low rates of clinical recognition of new-onset hypertension in the general population[20] including in younger women.[25] A previous EMR-based study found that over 2-thirds of non-pregnant younger women with multiple BPs of 140/90 mm Hg or higher did not receive a hypertension diagnosis or treatment within a year.[25] Although we cannot determine with absolute certainty whether a woman had hypertension based solely on EMR data, we observed evidence suggestive of hypertension in many women with repeated high BPs who did not receive a diagnosis: 76.5% had 3 or more separate visits with recorded high BPs, 20% experienced a severely elevated BP, and for 58% there was a clinical statement in their medical record about hypertension. Given that few women in this group were treated, it is possible that a diagnosis may be more likely to be coded when a clinician decides to prescribe antihypertensive medications but more likely to be absent for untreated women. This finding suggests that studies relying on diagnosis codes alone may miss a substantial group of untreated hypertensive women, potentially resulting in an underestimate of prevalence of hypertension in pregnancy.

In pregnancies identified as hypertensive in this study, 36% were treated. This is not surprising given that US guidelines do not recommend treatment for women with mild to moderate hypertension;[8] in contrast to a number of international guidelines,[27,28] including from the International Society for the Study of Hypertension in Pregnancy (ISSHP),[29] current US guidelines recommend treatment for women with BP 160/110 mmHg or above. A prior study among publicly insured U.S. pregnancies reported that only 45% of women treated pre-existing hypertension received any outpatient hypertension treatment during pregnancy.[12] The treatment rate was lower in our study as we included both new and preexisting hypertension and women with newly developed hypertension may be less likely to initiate an antihypertensive medication.

The goal of our study was not to assess prevalence of hypertensive disorders in pregnancy. Rather, we presented a hypertension definition used in our parent study to identify hypertensive pregnancies for whom a treatment decision could influence pregnancy outcomes. We attempted to achieve high specificity through requiring strict timing of

diagnoses, BP and receipt of pharmacologic treatment. This strategy resulted in exclusion of some pregnancies that would have been identified as hypertensive using diagnosis or treatment-based approach. This case definition, however, can be modified to identify a broader group of hypertensive pregnancies to suit new research objectives. Based on our chart review results, some possible strategies include allowing: (1) women with multiple diagnosis codes to qualify if they also had high BP or fills of antihypertensive medications; (2) women on methyldopa or labetalol to qualify if they also had a hypertension diagnosis in pregnancy.

The study has several limitations. First, we used BP from routine clinical care, which may not be measured according to the optimal (research) standard.[30] KP staff have received proper training and, at many sites, certification in BP measurement. Equipment is professionally monitored and recalibrated as needed. However, we recognize that some shortcomings may persist. These BP data reflect the best available data in real-world settings and are used for making clinical decisions. Also because we relied on clinical BP, we may have included women with repeated high BP at clinic who had normal BP at home (known as white-coat or transient gestational hypertension depending on timing of detection).[28] Due to uses of diagnosis codes and medication fills, misclassification may also occur when a provider misdiagnosed and/or started treating a woman who was not truly hypertensive. In the general population, white-coat hypertension accounts for 15–30% of people with elevated office BP and whether to treat these patients is controversial.[31] However, high BP can rapidly progress to more serious hypertension in an ongoing pregnancy and the U.S. clinical guideline from the ACOG did not attempt to distinguish white-coat hypertension or transient gestational hypertension from other hypertensive disorders in pregnancy.[8] The ISSHP guideline while acknowledging these 2 categories also cautioned that they can convey risk of preeclampsia.[29] Hence, from a research point of view, we believe it is still worthwhile to identify women with repeated high BP values in the clinic, including those who may have white-coat hypertension or transient gestational hypertension, to better understand their risk of adverse pregnancy outcomes. Second, we included women delivering in three U.S. large integrated healthcare delivery systems, most of whom were privately insured. Results may be different in other settings and populations. Third, we limited our study to hypertension that emerged by 35 weeks 6 days gestation and thus characteristics of our cohort, including likelihood of receiving a diagnosis code at delivery, may not represent pregnancies with late onset hypertension.

Our study is among the first to evaluate an approach including BP from the EMR to identify women with hypertension during pregnancy. Other strengths include a large population with diverse race/ethnicity background, drawing on data from three healthcare systems, and conducting medical record review to understand reasons that women with some evidence of hypertension did not meet our case definition.

In summary, using EMR data, we found it feasible to implement a case definition for hypertension in pregnancy based on a combination of BP, diagnosis codes and pharmacy fills. Notably, 28% of women identified as hypertensive using this approach would have been missed by approaches using diagnosis codes alone. Many women identified by our method experienced severely elevated BP, showing the importance of including these women

in future studies. Future research should also examine pregnancy outcomes among women who would be overlooked by approaches only using diagnosis codes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Highlights:

- Blood pressure (BP) was used with claims data to identify hypertensive pregnancies.
- 28% of pregnancies with ≥2 high BPs did not have a hypertension diagnosis code.
- Future studies should seek to incorporate BP to study hypertension in pregnancy.

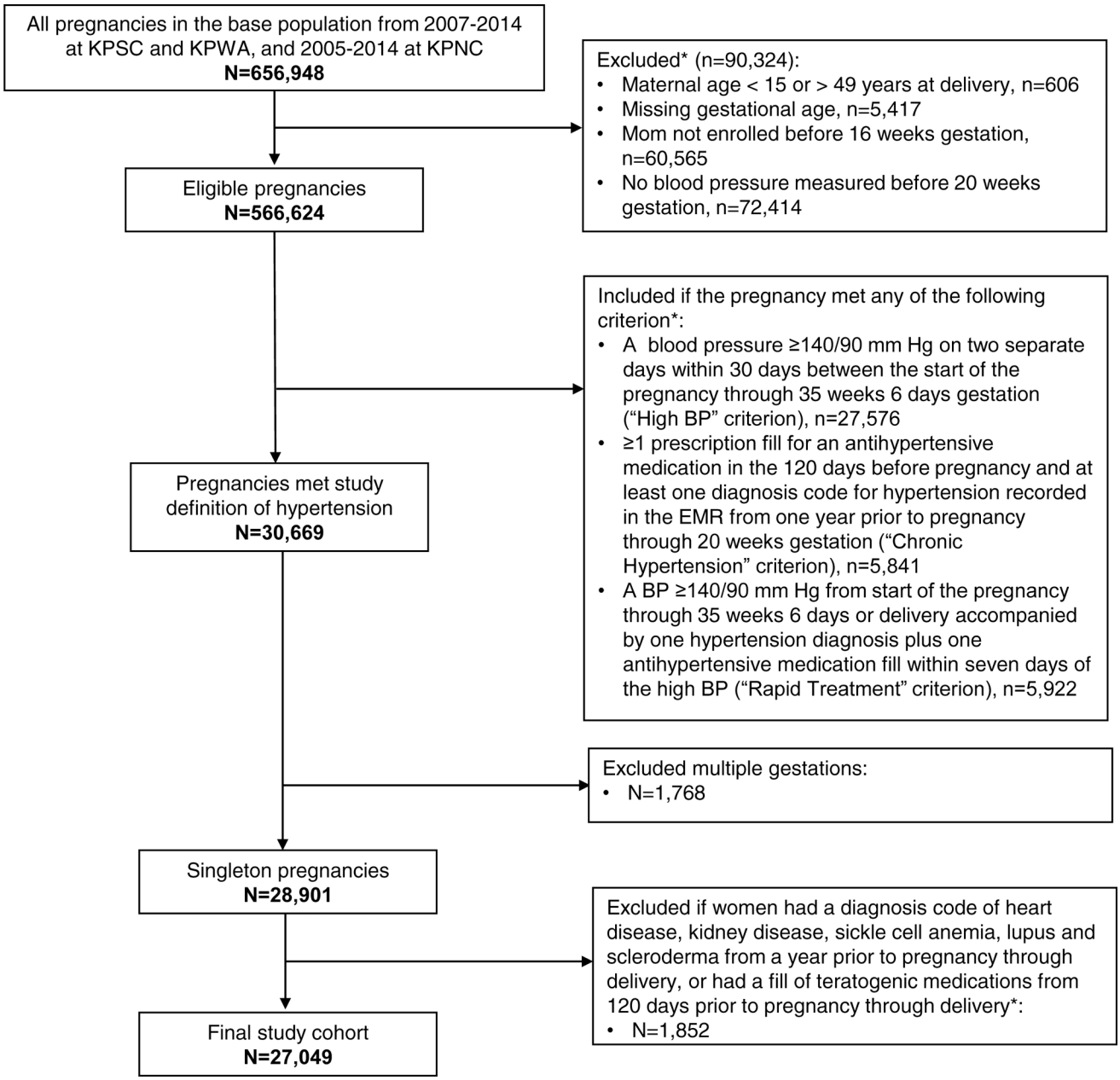

Figure 1. Identification of the study cohort.

* Criteria not mutually exclusive. KPNC: Kaiser Permanente Northern California; KPSC: Kaiser Permanente Southern California; KPWA: Kaiser Permanente Washington.

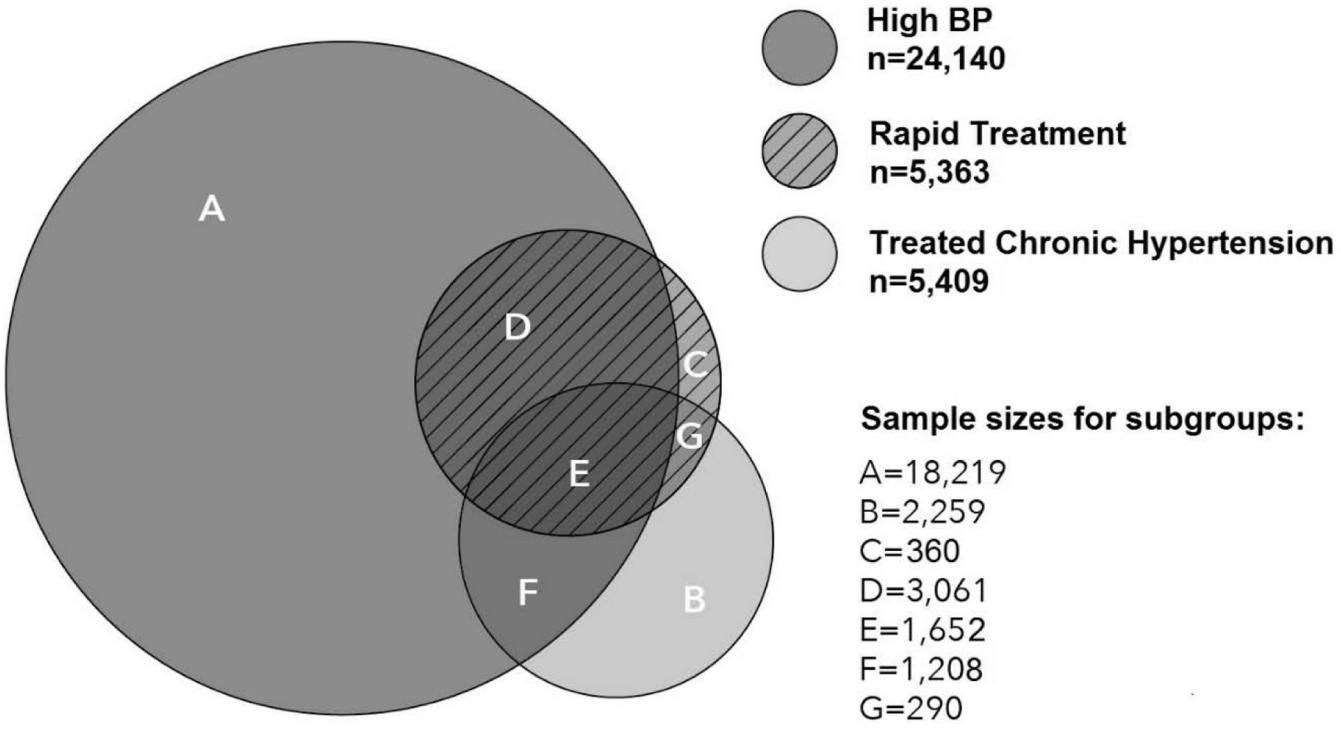

Figure 2. Groups identified by each criterion in study case definition for hypertension

High BP criterion: 2 or more BP ≥ 140/90 within 30 days from the start of pregnancy through 35 weeks 6 days; Treated chronic Hypertension criterion: 1 antihypertensive medication fill within 120 days prior to pregnancy and 1 hypertension diagnosis code from 1 year prior to pregnancy through 20 weeks gestation; Rapid Treatment criterion: 1 high BP (≥ 140/90) from the start of pregnancy through 35 weeks 6 days accompanied by 1 diagnosis code and 1 antihypertensive medication fill all within 7 days.

Table 1.

Characteristics of women with hypertension in pregnancy, 2005–2014

Maternal Characteristics	Hypertensive Cohort		Pregnancies Meeting Each Hypertension Case Criterion*					
			High BP		Chronic Hypertension		Rapid Treatment	
	n= 27,049		n=24,140		n=5,409		n=5,363	
	n	*%*	*n*	*%*	*n*	*%*	*n*	*%*
Age [in years, mean, (Standard deviation)]	31.7 (5.9)		31.4 (5.9)		34.7 (4.9)		33.3 (5.4)	
Race/Ethnicity								
White	9,801	(36.4)	8,887	(37.0)	1,597	(29.7)	1,715	(32.2)
Hispanic	8,531	(31.7)	7,650	(31.9)	1,624	(30.2)	1,534	(28.8)
Asian	4,483	(16.7)	3,858	(16.1)	1,219	(22.6)	1,141	(21.4)
African American	3,905	(14.5)	3,446	(14.3)	903	(16.8)	888	(16.7)
Other	192	(0.7)	173	(0.7)	39	(0.7)	48	(0.9)
Missing or unknown †	137		126		27		37	
At least college education								
Yes	10,607	(40.9)	9,348	(40.4)	2,352	(45.5)	2,094	(40.9)
Missing †	1,118		990		237		247	
Smoked during pregnancy	1,551	(5.7)	1,406	(5.8)	256	(4.7)	273	(5.1)
Parous	14,190	(54.8)	12,295	(53.3)	3,463	(65.7)	3,139	(60.6)
Missing parity †	1,169		1,089		141		181	
Had pre-existing diabetes	2,082	(7.7)	1,713	(7.1)	860	(15.9)	539	(10.1)
Had Medicaid insurance	1,879	(6.9)	1,710	(7.1)	355	(6.6)	376	(7.0)
Pre-pregnancy BMI								
<25 kg/m^2	4,688	(18.7)	4,211	(18.8)	740	(15.1)	677	(13.8)
25–29 kg/m^2	6,142	(24.6)	5,491	(24.5)	1,132	(23.2)	1,133	(23.1)
≥ 30 kg/m^2	14,180	(56.7)	12,744	(56.8)	3,014	(61.7)	3,086	(63.0)
Missing †	2,039		1,694		523		467	
Infant sex								
Male	13,938	(52.1)	12484	(52.3)	2743	(51.3)	2753	(52.1)
Missing [a]	288		262		64		83	

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[*] Women meeting multiple criteria of the hypertension case definition were included in each group.

High BP criterion: 2 or more BP ≥ 140/90 within 30 days from the start of pregnancy through 35 weeks 6 days; Treated chronic Hypertension criterion: 1 antihypertensive medication fill within 120 days prior to pregnancy and 1 hypertension diagnosis code from 1 year prior to pregnancy through 20 weeks gestation; Rapid Treatment criterion: 1 high BP (≥ 140/90) from the start of pregnancy through 35 weeks 6 days accompanied by 1 diagnosis code and 1 antihypertensive medication fill all within 7 days.

[†] Women with missing value were not included in the denominator for percentage calculation.

Table 2.

Diagnosis, treatment and blood pressure of the hypertensive cohort by case definition

	Hypertensive cohort		Pregnancies Meeting Each Hypertension Case Criterion*					
			High BP		Treated chronic Hypertension		Rapid Treatment	
	n= 27,049		n=24,140		n=5,409		n=5,363	
	n	*%*	*n*	*%*	*n*	*%*	*n*	*%*
Received a hypertension diagnosis during pregnancy	19,298	(71.3)	16,581	(68.7)	5,140‡	(95.0)	5,363	(100.0)
First diagnosis recorded prior to 20 weeks†	8,938	(33.0)	6,602	(27.4)	4,647	(85.9)	4,056	(75.6)
First diagnosis recorded after 20 weeks	10,360	(38.3)	9,979	(41.3)	493	(9.1)	1,307	(24.4)
At the delivery hospitalization§	16,039	(59.3)	13,754	(57.0)	4,397	(81.3)	4,679	(87.2)
Filled antihypertensive medications during pregnancy	9,762	(36.1)	7,498	(31.1)	4,472	(82.7)	5,362	(100)
Median gestational age at first prescription (interquartile range, in weeks)	10.4 (5.3,24.1)		12.2 (6.1,28.4)		6.3 (3.6, 10.3)		11.0 (5.9,25.4)	
Visits with high BP during pregnancy¶								
Anytime during pregnancy								
≥1 visit with high BP	26,355	(97.4)	24,140	(100)	4,715	(87.2)	5,363	(100)
≥2 visits with high BP	25,593	(94.6)	24,140	(100)	4,035	(74.6)	5,226	(97.5)
Median time between first and last visits with high BP (interquartile range, in weeks)	31.4 (28.3,34.0)		31.3 (28.1,34.0)		31.9 (29.1,34.4)		30.9 (27.6, 33.7)	
≥1 visit with severe high BP	11,226	(41.5)	10,774	(44.6)	1,981	(36.6)	3,322	(61.9)
From 20 weeks gestation to delivery								
≥1 visit with high BP	20,889	(77.2)	19,922	(82.5)	3,265	(60.4)	4,705	(87.7)
≥1 visit with severe high BP	5,639	(20.8)	5,588	(23.1)	9,24	(17.1)	1,989	(37.1)

*Women meeting multiple criteria of the hypertension case definition were included in each group.

High BP criterion: 2 or more BP ≥ 140/90 within 30 days from the start of pregnancy through 35 weeks 6 days; Treated chronic Hypertension criterion: 1 antihypertensive medication fill within 120 days prior to pregnancy and 1 hypertension diagnosis code from 1 year prior to pregnancy through 20 weeks gestation; Rapid Treatment criterion: 1 high BP (≥ 140/90) from the start of pregnancy through 35 weeks 6 days accompanied by 1 diagnosis code and 1 antihypertensive medication fill all within 7 days.

†This means the earliest time in pregnancy a diagnosis was recorded, which may not be the first time a woman's hypertension was recognized in her lifetime.

‡All pregnancies that met the Treated chronic hypertension criterion had a diagnosis between 1 year prior to pregnancy through 20 weeks. When restricted to time during pregnancy, some (n=269) did not have a diagnosis code, and some had a first code after 20 weeks.

§Defined as a hypertension diagnosis in an inpatient setting from three days before delivery through delivery.

¶High blood pressure (BP) defined as BP ≥ 140/90 mm Hg and severe high BP defined as BP ≥ 160/110 mm Hg. Excluding BP measured on the delivery day.

Table 3.

Pregnancies with multiple high blood pressures without a diagnosis (Set B)-Treatment and Blood pressure

	All n= 7,559	
	n	***%***
Received antihypertensive medication fills during pregnancy	585	(7.7)
Gestational age at first prescription (median, interquartile range in weeks) *	20.7 (9.4,31.7)	
Visits with high BP during pregnancy †		
Anytime during pregnancy		
≥2 visits with high BP	7,559	(100)
Median time between first and last visits with high BP (interquartile range, in weeks)	32.3 (29.4, 35.0)	
≥3 visits with high BP	5,786	(76.5)
≥1 visit with severe high BP	1,537	(20.3)
From 20 weeks gestation to delivery		
≥1 visit with high BP	4,990	(66.0)
≥1 visit with severe high BP	480	(6.4)

* Calculation of median and interquartile was restricted to pregnancies with prescription fill respectively.

† High blood pressure (BP) defined as BP ≥ 140/90 mm Hg and severe high BP defined as BP ≥ 160/110 mm Hg. Excluding BP measured on the delivery day.

Table 4.

Medical record review on discrepant cases meeting different hypertension identification algorithms

Set A: Among pregnancies with multiple hypertension diagnosis codes during pregnancy and thus would have been identified by a diagnosis-based approach, those that did not meet our hypertension case definition

- Of the base 566,624 eligible pregnancies, 17,742 had multiple hypertension diagnosis codes during pregnancy. Of them, 3,933 (22.2%) were not identified as hypertensive by our approach.
- Of the 50 charts reviewed from this group:
  - 8 (16.0%) filled antihypertensive medications. They did not meet our definition of hypertension either because the timing of the fill and the diagnosis code was not within our specified time window (n=4) or prescriptions were filled outside of KP facility.
  - 14 (28.0%) had 2 or more BP of 140/90 or higher. They were not identified by our approach because none of these high BP were within 30 days.

Set B: Among pregnancies met our High BP criterion, those did not have a hypertension diagnosis code. They would have been missed by a diagnosis-based approach.

- Of the 24,140 pregnancies met the High BP criterion (2 or more BP ≥140/90), 7,559 (31.3%) did not receive a hypertension diagnosis code.
- Of the 55 charts reviewed from this group:
  - 32 (58.1 %) had a clinical statement about hypertension, white coat hypertension or high BP.
  - 3 (5.5%) filled antihypertensive medications
  - 13 (23.6%) had documentations of acute illness in situations when 1 of their high BP was measured

Set C: Among pregnancies treated with antihypertensive medications, those did not meet our hypertension case definition.

- Of the base 566,624 eligible pregnancies, 7,737 were treated with methyldopa or labetalol.

  Of them, 741 (9.6%) were not identified as hypertensive by our approach.
  - Of the 20 charts reviewed from this group:
    - 15 (75.0%) had documentation in the charts that they were using the medication to treat hypertension.
    - 10 (50.0%) received a diagnosis within 7 days of an antihypertensive medication fill, but none also had a high BP within this time window to qualify our Rapid Treatment criterion.
    - 6 (30.0%) had 2 or more BP ≥140/90. Of them, 3 had high BP within 30 days and thus would have met our High BP criterion. However, the BP information was found in clinical notes only (not in structured electronic medical record data), due to reasons such as receiving care outside of our facility or self-reporting BP.
- Of the base 566,624 eligible pregnancies, 5,288 were treated with other antihypertensive medications. Of them, 2,451 (46.4%) were not identified as hypertensive by our approach.
  - Of the 25 charts reviewed from this group:
    - 4 (16.0%) had documentation in the charts that they were using the medication to treat hypertension
    - 2 (8.0%) received a diagnosis within 7 days of an antihypertensive medication fill, but neither also had a high BP within this time window to quality our Rapid Treatment criterion.
    - None had 2 or more BP ≥140/90 any time during pregnancy