Development and Validation of a Hypertension Prevalence Estimator Tool For Use in Clinical Settings

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Health systems are well positioned to identify and control hypertension among their patients. However, almost one third of US adults with uncontrolled hypertension are currently receiving medical care and are unaware of being hypertensive. This study describes the development and validation of a tool that health systems can use to compare their reported hypertension prevalence with their expected prevalence. Tool users provide the number of patients aged 18 to 85 years treated annually, stratified by sex, age group, race/ethnicity, and comorbidity status. Each stratum is multiplied by stratum-specific national prevalence estimates and the amounts are summed to calculate the number of expected hypertensive patients. The tool's validity was assessed by applying samples from cohorts with known hypertension prevalence; small differences in expected vs actual prevalence were identified (range, −3.3% to 0.6%). This tool provides clinically useful hypertension prevalence estimates that health systems can use to help inform hypertension management quality improvement efforts. *J Clin Hypertens (Greenwich).* 2016;18:750–761. Published 2016. This article is a U.S. Government work and is in the public domain in the USA.

Hypertension is a significant risk factor for cardiovascular disease (CVD) and mortality.[1–4] Effective hypertension management, resulting in a reduction in blood pressure (BP), has been shown to greatly decrease the incidence of cardiovascular events.[2–4] However, during 2003 to 2010, of the estimated 66.9 million US adults with hypertension, an estimated 35.8 million (53.5%) did not have their hypertension controlled.[5] Moreover, among those with uncontrolled hypertension, 32.0 million (89.4%) reported having a usual source of health care, including 11.7 million (32.7%) who had a usual source of care but were unaware of being hypertensive.[5]

Health systems typically use their administrative claims data and patients' medical health records to determine their patient population's hypertension prevalence and track and report the effectiveness of their hypertension control efforts. However, these methods may not address identification of hypertensive adults who receive care within the health system but remain undiagnosed. If health systems are not identifying all of their patients in need of hypertension management, they are missing opportunities to improve their patients' health.

The purpose of this study is to describe and assess the statistical and clinical validity of a hypertension prevalence estimator tool (Estimator Tool) that was developed using data from the National Health and Nutrition Examination Survey (NHANES). This tool will allow health systems to calculate the expected hypertension prevalence among their ambulatory care patient population, based on the patients' demographic profile and prevalence of leading hypertension risk factors. Health systems could use this tool to initiate quality improvement processes that assess whether improvements in the diagnosis and management of people with hypertension are needed.

METHODS

Survey and Sample Description
We developed the Estimator Tool using data from NHANES, a complex, multistage probability sample of the US civilian, noninstitutionalized population.[6] To obtain statistically stable estimates, we analyzed data from seven 2-year NHANES cycles (1999–2012) in which a total of 39,175 participants aged 18 years and older were interviewed and examined. To most closely reflect the clinical population of interest, we excluded pregnant women (ie, women at risk for gestational hypertension; n=1398) and participants with no reported visit to their primary healthcare provider within the past year (ie, people not currently in care; n=6415), for a total eligible sample size of 31,362 participants. Of these, 1136 participants were missing BP measurements or information on self-reported current use of antihypertensive medication and 2368 participants were missing data on other covariates of interest, yielding a final analytic sample of 27,858 participants. All analyses using the NHANES data were conducted using statistical software (SUDAAN, Release 11; RTI International, Research Triangle Park, NC) to account for sampling weights and to adjust variance estimates for the multistage, clustered sample design.

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BP Measurement and Hypertension Definition

A maximum of three BP readings were measured for each participant using a mercury sphygmomanometer (HgS) and auscultatory method. The mean of these recorded values was used to represent the participant's systolic BP (SBP) and diastolic BP (DBP).[7] For those participants with only a single BP reading, that measurement was used. We defined participants as being hypertensive if they had an average SBP ≥140 mm Hg or an average DBP ≥90 mm Hg[8] or self-reported current use of BP-lowering medication, defined as an answer of "yes" to both of the following questions: "Because of your high BP/hypertension, have you ever been told to take prescribed medicine?" and "Are you currently taking medication to lower your BP?"[9] Participants were considered to be aware of their hypertension status if they reported receiving a hypertension diagnosis from their healthcare provider, which was defined as an answer of "yes" to the question: "Have you ever been told by a doctor or other health professional that you had hypertension, also called high blood pressure?" A similar measure of primary healthcare providers' awareness of participants' hypertension status was not available.

Logistic Regression Model Development

We developed a logistic regression model that incorporated literature-supported hypertension risk factors and selected variables that were found to be statistically associated (*P*<.05) with hypertension among NHANES participants. We included the following variables in the final model: age,[8,10,11] sex,[11] race/ethnicity,[1,5,11] income and education status,[12] obesity status based on body mass index,[8,10,13,14] total cholesterol level status,[15] prior history of CVD,[8,16] diagnosed diabetes status,[8,10] and chronic kidney disease (CKD) status[8,10] (Table I). We used the final model to estimate the predicted marginal prevalence for each subgroup.

Estimator Tool Development

We limited the number of variables included in the Estimator Tool to six to minimize the number of data elements users would have to enter into the tool. The following variables were selected because they had the strongest association with hypertension prevalence within the regression model (ie, largest beta coefficients) and the greatest likelihood of consistent collection within health systems: sex, age group (18–44, 45–64, 65–74, and ≥75 years), race/ethnicity (non-Hispanic white, non-Hispanic black, Hispanic, or other), and diabetes, CKD, and obesity status. Of note, prior to 2007, NHANES only reported data specific to Mexican Americans; other Hispanics were included in the "Other" race/ethnicity category and cannot be differentiated. Therefore, we considered Mexican Americans to represent all Hispanics during 1999 to 2006 within the tool. We also included sex because we found a significant statistical interaction with age in the hypertension prevalence model (*P*<.001). We performed trend analyses to ensure that the relationship between the hypertension and risk factor prevalence did not change during 1999 to 2012 (*P*≥.05).

To mimic conditions where patients may have undiagnosed diabetes, we defined NHANES participants as being "diagnosed diabetic" if they reported being told by a doctor that they had diabetes, defined as an answer of "yes" to the question "Other than during pregnancy, have you ever been told by a doctor or health professional that you have diabetes or sugar diabetes?"[9] Had we used a definition based on participants' clinical measures (eg, hemoglobin A_{1c} values), the diabetes prevalence potentially could have been around 12% greater.[17] We defined CKD as participants having: (1) an estimated glomerular filtration rate <60 mL/min per 1.73 m^2 using the Chronic Kidney Disease Epidemiology Collaboration equation[18] or (2) albuminuria (albumin-to-creatinine ratio ≥30 mg/g). A similar measure of "diagnosed CKD" status is not available via NHANES to mimic the structure of the diagnosed diabetes variable. We defined obesity as a body mass index ≥30 kg/m^2.[7] To decrease the burden on the Estimator Tool user, we grouped the comorbidities together into one variable with the following categories: none, one, or two or three. Finally, we calculated weighted hypertension prevalence estimates and 95% confidence intervals (CIs) stratified by sex, age group, race/ethnicity, and comorbidity status.

Use of the Estimator Tool

Users of the tool are instructed to provide the number of ambulatory care patients that fall within each of the sex, age group, race/ethnicity, and comorbidity status strata, which are then multiplied by the expected prevalence for each stratum to arrive at the number of patients expected to have hypertension. We describe the suggested definitions health systems can use for each Estimator Tool element and methods for collecting BP measurements in e-Figure 1. We added a category of "Missing" to the race/ethnicity stratum if the user has missing race/ethnicity data; the mean hypertension prevalence estimate for all race/ethnicities combined, by comorbidity status, is applied to this category and assumes that the health system has a racial/ethnic distribution similar to the nation. In addition, we included an age cap of 85 years to align with other health system reporting requirements. NHANES, however, codes all participants aged 80 years and older as being aged 80 years for confidentially reasons; therefore, some of the participants used to compute the hypertension prevalence estimates for those aged 75 to 85 years are older than 85 years.

The tool sums the estimated number of hypertensive patients within each stratum and divides the sum by the size of the patient population to determine the health system's expected hypertension prevalence. The 95% CIs for the expected prevalence are calculated using the standard variance formula applied to this binomial mixture model.[19]

TABLE I. Logistic Regression Model With Significant Predictors of Hypertension Prevalence, NHANES 1999–2012 (N=27,858)

	Beta Coefficient	SE	P Value	Predicted Hypertension Prevalence %	SE	Proportion of the Population
Intercept	−2.0671	0.0622	<.001			
Sex						
Male	referent			33.6	0.7	45.5
Female	−0.6636	0.0761	<.001	32.0	0.6	54.5
Age group, y						
18–44	referent			15.0	0.5	46.1
45–64	1.1457	0.0736	<.001	37.9	0.8	35.3
65–74	1.7613	0.0951	<.001	54.8	1.1	10.7
75+	1.9776	0.0888	<.001	62.1	1.2	8.0
Race/ethnicity						
Non-Hispanic white	referent			32.0	0.6	73.0
Non-Hispanic black	0.6824	0.0513	<.001	42.6	0.8	10.6
Hispanic	−0.2553	0.0607	<.001	28.3	0.8	11.2
Other	0.1056	0.0881	.233	33.5	1.4	5.2
Education						
<College graduate	referent			34.8	0.5	62.9
College graduate	−0.2405	0.0483	<.001	31.0	0.8	25.5
<25 years of age	−1.5740	0.1554	<.001	14.5	1.5	11.6
Household income						
<$75k	referent			34.0	0.6	61.8
≥$75k	−0.1251	0.0659	.060	32.1	1.0	15.8
Missing income	−0.2679	0.0493	<.001	30.0	0.7	22.4
Obesity[a]						
Yes	0.8166	0.0438	<.001	40.9	0.7	33.6
No	referent			28.2	0.6	66.4
High cholesterol[b]						
Yes	0.5109	0.0419	<.001	37.6	0.8	32.0
No	referent			29.7	0.5	68.0
History of cardiovascular disease[c]						
Yes	0.4500	0.0778	<.001	39.1	1.2	7.8
No	referent			32.2	0.6	92.3
Diabetes[d]						
Yes	0.5824	0.0639	<.001	41.0	1.0	9.2
No	referent			31.8	0.5	90.8
Chronic kidney disease[e]						
Yes	0.7462	0.0517	<.001	42.8	1.0	15.4
No	referent			30.8	0.5	84.6
Sex and age group interaction, y						
Male, 18–44	referent			19.1	0.7	21.1
Male, 45–64	referent			38.5	1.1	16.2
Male, 65–74	referent			51.2	1.7	4.9
Male, 75+	referent			55.7	1.5	3.3
Female, 18–44	referent			11.6	0.6	25.0
Female, 45–64	0.6079	0.1038	<.001	37.4	1.0	19.0
Female, 65–74	0.9821	0.1279	<.001	57.8	1.4	5.8
Female, 75+	1.2508	0.1249	<.001	67.4	1.5	4.7

Abbreviations: NHANES, National Health and Nutrition Examination Survey; SE, standard error. [a]Body mass index ≥30.0 kg/m^2. [b]Reported being told by a doctor that they had high cholesterol or classified as such according to the Third Report of the National Cholesterol Education Program Adult Treatment Panel III with a total cholesterol ≥240 mg/dL. [c]Reported having a history of coronary heart disease, myocardial infarction, stroke, or angina. [d]Reported being told by a doctor that they had diabetes. [e]Had an estimated glomerular filtration rate <60 mL/min per 1.73 m^2 or albumin-to-creatinine ratio ≥30 mg/g.

Estimator Tool Performance Testing

We used two criteria to test the performance of the tool's ability to estimate the expected prevalence compared with the observed prevalence. First, we used chi-square tests to assess significant independence between the predicted and observed prevalence ($P<.05$). In addition, we describe the absolute difference between the predicted and observed values to better understand the clinical utility of the tool. We evaluated the tool's internal validity by applying the unweighted values from three samples each of 1500, 3000, and 6000 NHANES participants, randomly selected without replacement. These sample sizes were chosen based on a typical physician's panel size being around 1500 patients.[20] To assess the tool's external validity, we pooled participants from four studies with population-based samples: the Jackson Heart Study[21] (JHS); the Arkansas Cardiovascular Health Examination Survey[22] (ARCHES); the National Heart, Lung, and Blood Institute Hispanic Community Health Study/Study of Latinos[23] (HCHS); and the Multi-Ethnic Study of Atherosclerosis[24] (MESA). Characterizations of participants were based on their baseline data. MESA participants were free of clinical CVD at baseline. The other three studies had no CVD-related exclusion criteria. We chose these studies, because, unlike data from health systems, they include data on both self-reported (ie, diagnosed) and measured hypertension status. Health systems may be missing accurate data on the measured hypertension status of their patient population. We combined the data from these studies to ascertain the tool's performance among diverse samples that include multiple race-ethnic minority groups and likely reflect the patient populations seen within health systems. We then applied the unweighted values from three samples each of 1500, 3000, and 6000 randomly selected participants from these pooled studies. Table II describes the characteristics of the four pooled external cohorts compared with the weighted NHANES population.

Similar to NHANES, the four external surveys used protocol-driven methods to collect BP during one clinic visit and measured participants arm circumference to ensure a properly sized BP cuff was used. We used each studies' final reported SBP and DBP values to determine participants' hypertension status; how the final BP values attributed to each participant were determined differed across the studies. The JHS used the average of two BP readings obtained using a random zero HgS and auscultatory technique. The other three external studies used an Association for the Advancement of Medical Instrumentation-validated automated oscillometric device (AOD) to measure BP. ARCHES and HCHS used an average of three BP measures obtained using an OMRON HEM-907 XL device (Omron Healthcare, Inc, Lake Forest, IL). MESA used the average of the second and third BP measures obtained using a Dinamap PRO 100 device (Critikon, Tampa, FL). Additional modifications were made to some of the definitions used to correspond with how the external datasets collected their data. These modifications are described in Table II.

RESULTS

The hypertension prevalence among NHANES participants who were in care was 32.9% (95% CI, 31.9–34.0) and among the pooled external cohort was 46.2% (unadjusted) and 39.1% (adjusted by age, sex, and race/ethnicity to the 1999–2012 weighted NHANES population) (Table II). Among the NHANES participants, hypertension prevalence estimates were affected by each stratum of the tool (Table III). As expected, increasing age had the strongest association with increased hypertension prevalence. Non-Hispanic blacks tended to have the highest hypertension prevalence in the younger age groups and, while less pronounced, they also had higher rates in the older age groups. Men tended to have higher prevalence at younger ages and women at older ages.

An estimated 18.6% of NHANES participants with hypertension who were in care were unaware of being hypertensive. Awareness varied by stratum (Figure). Comorbidity status affected hypertension prevalence among both men and women in every age group, with a stepwise increase in prevalence with each increase in the number of comorbidities. The largest relative impact of comorbidities on hypertension prevalence was observed among the youngest age groups. For example, compared with men and women aged 18 to 44 years with no comorbidities (hypertension prevalence: 8.2% [95% CI, 7.2–9.2] and 3.8% [95% CI, 3.1–4.7], respectively), similar aged men and women with one comorbidity had hypertension prevalence rates 2.6 (21.1% [95% CI, 18.6–23.9]) and 3.2 (12.1% [95% CI, 10.5–14.0]) times higher, respectively, and those with two or three comorbidities had rates 5.7 (46.5% [95% CI, 38.3–55.0]) and 9.9 (37.5% [95% CI, 31.4–43.9]) times higher. Moreover, those with two or three comorbidities typically had higher hypertension prevalence rates than those with no comorbidities in the next older age group. Finally, hypertension prevalence among younger non-Hispanic blacks appeared to be more strongly affected by comorbidity status than the other racial/ethnic groups. The relationship between hypertension prevalence and each element included in the tool did not change from 1999–2000 to 2011–2012 (Table IV).

Table V summarizes the outcomes of the validation testing. The internal validity of the Estimator Tool was strong as there were no statistically significant differences between the expected and observed hypertension prevalence among the randomly selected and unweighted NHANES participants. Clinically, the differences ranged from underestimating the prevalence by −1.9% to overestimating the prevalence by 0.6%, with the differences decreasing as the random sample sizes increased. As for the external statistical validity assessment of the tool, the differences between the expected and observed prevalence ranged from an underestimate of −2.2% to −3.3% for the random samples with 1500 participants and −1.8% to −2.2% for the samples with

TABLE II. Characterization of the NHANES Cohort and Cohorts Used for External Validation

| | ARCHES | JHS | HCHS | MESA | Total Pooled Cohort | | NHANES (1999–2012)[b] |
					Unadjusted	Adjusted[a]	
Original cohort size, No.	1383	5301	16,415	6814	29,913	–	68,705
Effect of stepwise application of inclusion/exclusion criteria							
Aged 18–85 y	1369	5292	14,155	6814	27,630	–	39,175
Not pregnant	1369	5292	14,155	6814	27,630	–	37,777
Receiving primary health care	1003[c]	3813[d]	9960[e]	6278[f]	21,054	–	31,362[g]
Not missing race or sex	997[h]	3813[i]	9960	6278	21,048	–	31,362
Not missing hypertension status	994	3758	9870	6274	20,896	–	30,226
Not missing comorbidity data (final cohort)[j]	906	3716	9782	6256	20,660	–	27,858
Mean age (SD), y	57.6 (14.4)	56.9 (12.5)	47.3 (14.1)	62.2 (10.3)	54.0 (14.4)	–	47.1 (33.2)
Age category, %, y							
18–44	17.3	19.8	36.4	0.1	21.6	–	46.1
45–64	48.1	52.0	53.1	55.5	53.4	–	35.3
65–74	22.7	21.5	10.4	30.1	18.9	–	10.7
75–85[k]	11.8	6.7	0.1	14.3	6.1	–	8.0
Male, %	31.9	31.6	36.0	46.3	38.2	–	45.5
Race/ethnicity, %							
Non-Hispanic white	74.0	0.0	0.0	40.2	15.4	–	73.0
Non-Hispanic black	26.0	100.0	0.0	27.6	27.5	–	10.6
Hispanic	NA[h]	NA[i]	100.0	20.3	53.5	–	11.2
Other	0.0	0.0	0.0	12.0	3.6	–	5.2
Hypertension prevalence, %	62.4	66.4	35.2	49.1	46.2	39.1	32.9 (31.9–34.0)
Obesity prevalence, %	45.9	54.2	44.0	32.1	42.3	39.4	33.6 (32.5–34.6)
Diabetes prevalence, %	17.1	19.6	16.5	11.4	15.5	9.4	9.2 (8.7–9.7)
CKD prevalence, %[j]	21.4	15.6	13.9	20.1	16.4	13.2	15.4 (14.8–16.0)
Comorbidities, %							
None	39.5	34.8	45.0	51.8	45.0	50.7	55.0 (53.9–56.1)
One	40.7	44.8	38.8	35.1	38.9	38.0	34.2 (33.3–35.1)
Two or three	19.8	20.3	16.2	13.1	16.2	11.3	10.9 (10.3–11.4)
Mean BP (SD), mm Hg[l]							
Systolic BP	131.5 (19.6)	127.4 (18.3)	122.0 (18.3)	126.6 (21.4)	126.9 (19.2)	126.9 (17.7)	122.4 (22.6)
Diastolic BP	78.0 (11.4)	78.5 (10.6)	72.9 (10.9)	71.9 (10.2)	74.8 (10.8)	75.8 (10.5)	71.2 (15.7)

Abbreviations: ARCHES, Arkansas Cardiovascular Health Examination Survey; BP, blood pressure; CKD, chronic kidney disease; HCHS, National Heart, Lung, and Blood Institute Hispanic Community Health Study/Study of Latinos; JHS, Jackson Heart Study; MESA, Multi-Ethnic Study of Atherosclerosis; NA, not available; NHANES, National Health and Nutrition Examination Survey; SD, standard deviation. [a]Adjusted by age, sex, and race/ethnicity to reflect the distribution of the weighted 1999–2012 NHANES population. [b]Weighted values are shown for the unadjusted NHANES estimates. Confidence intervals (95%) are provided for the comorbidity prevalence estimates. [c]Reported having a medical home. [d]Reported having a doctor visit in the last year. [e]Reported having one or more doctor visits in the past 12 months. [f]Reported having a doctor's office as their main medical home. [g]Reported visit to their primary healthcare provider within the past year. [h]Ethnicity data were not provided. All participants were considered to be non-Hispanic for these analyses as, per the study leaders, approximately 98% of the cohort was non-Hispanic. [i]Ethnicity data were not provided. [j]To accommodate missing CKD-related data within the external datasets, participants had to have values for either estimated glomerular filtration rate or albumin to creatinine ratio to be included in the CKD prevalence estimates and the pooled cohort, not necessarily both. NHANES participants had to have both values available. [k]Age is top coded at 80 years for NHANES participants, therefore, this age group represents those aged 75 years and older. [l]Among those with recorded BP measures.

6000 participants. While these represent small clinical differences, the expected vs observed estimates were all significantly different, denoting a lack of agreement.

DISCUSSION
This study found that approximately one third of the US adult population receiving healthcare services has hypertension, of which almost one in five are unaware of their hypertensive status. Moreover, we found that the Estimator Tool is a potentially useful instrument that provides hypertension prevalence estimates that differ minimally from that observed among cohorts with known hypertension prevalence. Health systems can use the tool to initiate hypertension management quality improvement efforts and help improve the identification of undiagnosed hypertension among their patient

TABLE III. Hypertension Prevalence by Sex, Age, Race/Ethnicity, and Comorbidity Status Category, Among Adults Aged 18 Years and Older With a Primary Healthcare Visit Within the Past Year—NHANES, 1999–2012

Age, y	Race/Ethnicity	Number of Comorbidities	Hypertension Prevalence (95% CI)	
			Men	Women
18–44	Non-Hispanic white	0	8.4 (7.1–9.9)	3.5 (2.6–4.8)
		1	21.1 (17.8–24.7)	11.6 (9.3–14.4)
		2–3	38.2 (26.2–51.7)	37.3 (28.1–47.5)
	Non-Hispanic black	0	10.0 (8.0–12.4)	9.3 (7.3–11.9)
		1	27.8 (23.1–33.1)	17.3 (14.7–20.3)
		2–3	64.8 (51.5–76.1)	52.2 (41.6–62.6)
	Hispanic[a]	0	5.2 (3.6–7.4)	1.7 (0.9–3.3)
		1	13.9 (10.2–18.7)	7.9 (5.3–11.8)
		2–3	54.6 (42.6–66.1)	24.7 (15.8–36.4)
	Other	0	8.9 (5.2–14.7)	3.4 (1.8–6.3)
		1	25.9 (17.2–37.2)	12.4 (6.2–23.3)
		2–3	43.1 (13.7–78.4)	25.1 (8.5–54.6)
	Missing/Total[b]	0	8.2 (7.2–9.2)	3.8 (3.1–4.7)
		1	21.1 (18.6–23.9)	12.1 (10.5–14.0)
		2–3	46.5 (38.3–55.0)	37.5 (31.4–43.9)
45–64	Non-Hispanic white	0	32.3 (28.6–36.3)	26.8 (24.0–29.7)
		1	46.9 (42.7–51.1)	49.2 (44.8–53.6)
		2–3	70.9 (65.4–75.8)	67.3 (59.5–74.2)
	Non-Hispanic black	0	46.1 (41.4–50.8)	45.9 (40.3–51.7)
		1	60.0 (53.6–66.1)	66.4 (61.7–70.9)
		2–3	87.0 (81.1–91.3)	86.1 (81.9–89.4)
	Hispanic[a]	0	26.3 (20.8–32.7)	23.9 (18.6–30.3)
		1	44.0 (35.5–52.8)	38.3 (32.7–44.2)
		2–3	64.5 (53.3–74.2)	67.6 (60.0–74.4)
	Other	0	31.3 (21.4–43.2)	28.0 (20.0–37.7)
		1	50.1 (35.8–64.4)	58.7 (45.9–70.5)
		2–3	68.8 (39.2–88.3)	65.9 (45.2–81.9)
	Missing/Total[b]	0	32.9 (29.8–36.3)	27.9 (25.6–30.3)
		1	48.1 (44.6–51.7)	50.9 (47.5–54.4)
		2–3	72.4 (68.4–76.0)	71.3 (66.5–75.7)
65–74	Non-Hispanic white	0	51.9 (46.4–57.4)	55.3 (50.4–60.2)
		1	64.2 (58.6–69.4)	68.8 (63.4–73.7)
		2–3	77.0 (69.5–83.1)	90.0 (84.8–93.5)
	Non-Hispanic black	0	71.5 (62.9–78.8)	69.7 (57.9–79.3)
		1	80.9 (72.9–87.0)	88.0 (82.2–92.0)
		2–3	86.1 (79.6–90.7)	92.1 (86.9–95.4)
	Hispanic[a]	0	41.1 (29.8–53.3)	65.3 (53.1–75.8)
		1	63.8 (50.4–75.3)	75.8 (64.2–84.5)
		2–3	74.5 (59.9–85.2)	84.5 (73.9–91.3)
	Other	0	68.5 (47.4–84.0)	48.5 (30.7–66.6)
		1	62.1 (37.9–81.5)	92.0 (76.9–97.5)
		2–3	80.2 (49.7–94.3)	93.5 (64.0–99.1)
	Missing/Total[b]	0	53.1 (48.4–57.8)	56.3 (52.0–60.6)
		1	65.4 (60.7–69.9)	71.8 (67.3–75.9)
		2–3	77.9 (71.9–82.8)	90.0 (86.2–92.8)
≥75[c]	Non-Hispanic white	0	58.2 (53.3–63.0)	69.3 (64.2–74.0)
		1	71.2 (67.1–75.0)	82.5 (79.2–85.3)
		2–3	77.5 (71.9–82.2)	87.5 (83.6–90.6)
	Non-Hispanic black	0	68.8 (54.1–80.4)	85.6 (70.5–93.7)
		1	89.8 (79.3–95.3)	84.1 (73.8–90.9)
		2–3	81.3 (69.3–89.3)	93.8 (87.3–97.1)
	Hispanic[a]	0	61.2 (48.1–72.9)	74.3 (55.4–87.0)
		1	73.0 (61.3–82.1)	88.5 (80.6–93.4)
		2–3	89.0 (76.5–95.3)	75.3 (61.5–85.4)

TABLE III. Hypertension Prevalence by Sex, Age, Race/Ethnicity, and Comorbidity Status Category, Among Adults Aged 18 Years and Older With a Primary Healthcare Visit Within the Past Year—NHANES, 1999–2012 (Continued)

			Hypertension Prevalence (95% CI)	
Age, y	Race/Ethnicity	Number of Comorbidities	Men	Women
	Other	0	34.6 (11.8–67.7)	80.6 (49.7–94.6)
		1	68.4 (47.0–84.0)	83.1 (62.6–93.5)
		2–3	58.8 (29.8–82.8)	85.2 (62.0–95.3)
	Missing/Total[b]	0	58.5 (54.0–62.8)	70.6 (65.8–74.9)
		1	72.2 (68.4–75.6)	82.8 (79.9–85.4)
		2–3	77.6 (72.7–81.9)	87.7 (84.3–90.3)

Abbreviations: CI, confidence interval; NHANES, National Health and Nutrition Examination Survey. [a]Prior to 2007, NHANES only reported data specific to Mexican Americans; other Hispanics were included in the "Other" race/ethnicity category and are not able to be differentiated. For these purposes, Mexican Americans were considered to represent all Hispanics during 1999–2006. [b]Added to accommodate those health systems that are unable to report their data by race/ethnicity or who may have some patients who lack a race/ethnicity classification. The hypertension prevalence estimate for all race-ethnicities, by comorbidity status, is applied to this category. [c]An age cap of 85 years is used in the Estimator Tool to better align with the clinical quality measures health systems are already reporting. However, NHANES codes all participants aged 80 years and older as being aged 80 years for confidentially reasons; therefore, some of the participants used to compute the hypertension prevalence estimates for those aged 75 to 85 years are older than age 85.
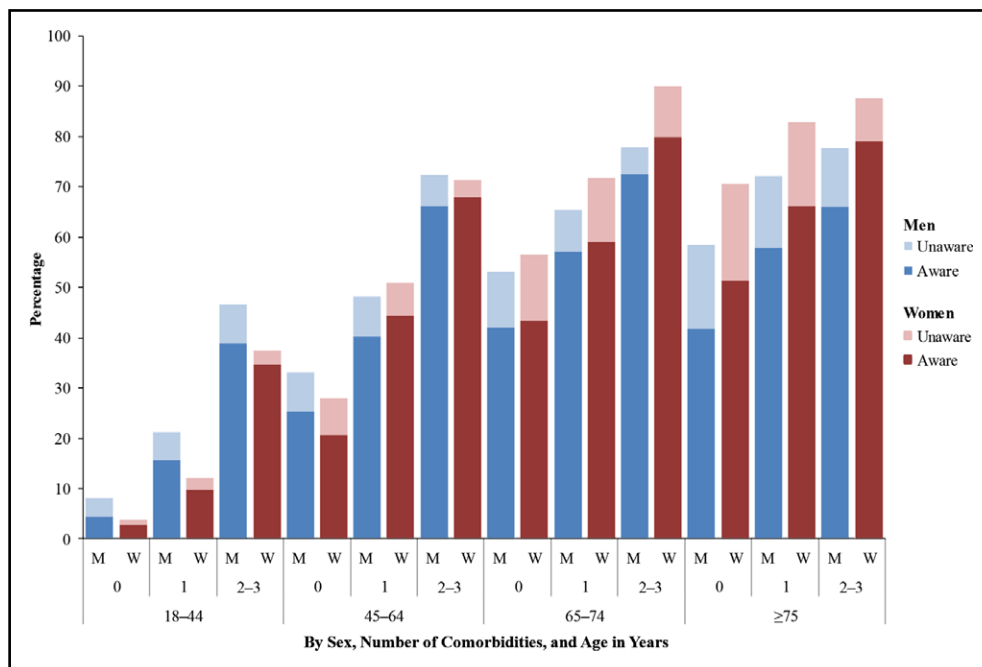

FIGURE. National hypertension prevalence estimates and awareness status among adults with a primary healthcare visit within the past year, by sex, age, and comorbidity status (National Health and Nutrition Examination Survey [NHANES], 1999–2012). [a]Represented as the number of comorbidities, including obesity, diagnosed diabetes, and chronic kidney disease.

population. Health systems are uniquely positioned to identify, treat, and control hypertension among patients who are currently within their care. These systems, no matter their size, should understand the expected scope of the hypertension burden among their patient population to ascertain whether they have adequately identified all of their patients with hypertension. Without first detecting all of the patients in need of hypertension management, the implementation of evidence-based

interventions to control hypertension using strategies tailored to the health system's patient population, including standardized hypertension treatment protocols,[25] team-based care initiatives that support clinical-community linkages,[26] or self-measured BP monitoring with clinical support,[27] may not be as effective in improving CVD outcomes.

While the validation testing of the tool with the pooled external cohort data resulted in statistically

TABLE IV. Trends in Hypertension Prevalence by Risk Factor Among Adults Aged 18 Years and Older With a Primary Healthcare Visit Within the Past Year, NHANES, 1999–2012

	Prevalence During Two-Year NHANES Cycle[a]							Trend P-Value
	99–00	01–02	03–04	05–06	07–08	09–10	11–12	
Total	32.2	30.6	34.8	33.3	33.6	33.4	32.6	0.39
Men	32.0	28.6	36.3	33.8	34.9	34.2	33.3	0.15
Women	32.3	32.4	33.5	32.8	32.5	32.7	32.0	0.83
Age, y								
18–44	10.7	8.4	11.1	11.1	11.8	9.7	10.7	0.59
45–64	39.2	38.2	46.0	42.5	42.6	43.9	42.5	0.16
65–74	66.8	67.5	69.0	68.6	66.4	67.8	61.6	0.20
≥75	78.8	76.1	76.4	73.1	75.6	77.8	76.3	0.73
Race/ethnicity								
Non-Hispanic white	30.3	28.9	33.8	31.6	33.1	31.8	31.0	0.38
Non-Hispanic black	44.6	47.5	45.4	46.8	44.5	46.1	45.9	0.99
Hispanic[b]	34.4	24.7	32.4	26.5	30.9	31.3	32.1	0.64
Other[c]	31.7	36.2	31.9	36.2	25.2	37.5	31.0	0.85
Comorbidities								
Obesity								
Yes	44.8	40.5	46.3	43.7	43.5	45.0	43.0	0.89
No	26.3	25.8	29.0	27.5	28.2	26.1	26.7	0.88
Diabetes								
Yes	53.2	49.1	52.7	60.6	55.0	60.6	58.8	0.10
No	31.0	29.2	33.0	31.2	31.4	30.9	29.8	0.81
CKD								
Yes	46.1	47.8	49.7	51.3	47.2	48.3	46.4	0.68
No	29.3	28.0	32.0	30.0	30.7	31.0	29.6	0.46
Number of comorbidities[d]								
None	23.9	23.2	26.4	24.2	24.8	23.4	23.8	0.72
1	38.9	36.6	40.7	37.6	39.7	39.2	36.8	0.88
2–3	58.8	55.7	58.6	62.1	53.6	63.4	60.4	0.25

Abbreviations: CKD, chronic kidney disease; NHANES, National Health and Nutrition Examination Survey. [a]Unadjusted prevalence by NHANES cycle. [b]Represents just Mexican Americans for 1999–2006 and all Hispanics from 2007–2012. [c]Includes non–Mexican American Hispanics from 1999–2006. [d]Comorbidities include obesity, diagnosed diabetes, and CKD.

significant differences in the expected vs observed hypertension prevalence values, we do not believe these differences were large enough to negate the clinical usefulness of the tool. This was especially the case for the larger samples of 6000 participants, which equates to a practice with about four full-time physicians, where the tool only underestimated hypertension prevalence by around 2%. In general, the Estimator Tool tended to underestimate the hypertension prevalence during both the internal and external validation testing. Therefore, it likely provides a conservative estimate, especially among populations with a hypertension prevalence greater than the US prevalence.

In 2012, the U.S. Department of Health and Human Services began Million Hearts (http://millionhearts.hhs.gov), an initiative aimed at preventing 1 million heart attacks, strokes, and other related CVD events by 2017.[28] The effective identification, treatment, and control of hypertension is a vital component in reaching the Million Hearts goal. To this end, Million Hearts has worked collaboratively with healthcare partners to identify strategies to detect those patients who have hypertension but are considered "hiding in plain sight"—those who are receiving care within the health system, but whose hypertension has gone undiagnosed and, therefore, unmanaged. Use of the Estimator Tool could be one of the first steps a health system takes in this process. If their expected hypertension prevalence is higher than their reported prevalence, one potential next step may be for the health system to use its medical record system to identify and follow up with patients with previous documentation of elevated BP who have not received a hypertension diagnosis and may need additional screening. Additional quality improvement steps that health systems can take across the spectrum of hypertension management are outlined in the *Million Hearts Hypertension Control Change Package*.[29] Future evaluation of how the Estimator Tool was incorporated into and informed hypertension management quality improvement efforts and its accuracy in predicting hypertension prevalence within health systems should be conducted.

TABLE V. Internal and External Validity Testing Results for the Hypertension Prevalence Estimator Tool, by Random Sample Size

	Hypertension Prevalence, %		Percent Difference, Estimated– Observed	P-Value[a]
	Estimated (95% CI)	Observed		
Internal Validity				
NHANES random samples (n=1500)				
Sample 1	38.7 (36.3–41.2)	38.1	0.6	0.59
Sample 2	38.2 (35.8–40.7)	39.1	−0.9	0.50
Sample 3	38.1 (35.6–40.5)	40.0	−1.9	0.12
NHANES random samples (n=3000)				
Sample 1	37.7 (35.9–39.4)	37.5	0.2	0.86
Sample 2	38.4 (36.6–40.1)	39.2	−0.8	0.32
Sample 3	38.3 (36.6–40.0)	38.6	−0.3	0.73
NHANES random samples (n=6000)				
Sample 1	38.5 (37.3–39.7)	38.5	0.0	0.96
Sample 2	38.8 (37.5–40.0)	38.4	0.4	0.56
Sample 3	38.5 (37.3–39.8)	39.1	−0.6	0.36
External Validity				
Pooled random samples (n=1500)				
Sample 1	44.1 (42.7–45.5)	46.3	−2.2	0.080
Sample 2	44.7 (43.3–46.1)	48.0	−3.3	0.010
Sample 3	45.2 (43.8–46.6)	47.7	−2.5	0.054
Pooled random samples (n=3000)				
Sample 1	44.0 (43.0–45.0)	46.4	−2.4	0.008
Sample 2	43.2 (42.2–44.2)	45.5	−2.3	0.012
Sample 3	44.3 (43.3–45.2)	46.3	−2.0	0.024
Pooled random samples (n=6000)				
Sample 1	44.3 (43.6–45.0)	46.4	−2.1	0.001
Sample 2	43.9 (43.2–44.6)	45.7	−1.8	0.005
Sample 3	44.0 (43.3–44.7)	46.2	−2.2	<0.001

Abbreviations: CI, confidence interval; NHANES, National Health and Nutrition Examination Survey. [a]Chi-square test to assess the association between the expected prevalence estimates and the observed prevalence values.

STRENGTHS

The described tool has multiple strengths. First, it allows users to determine their estimated hypertension prevalence based on their own patients' aggregate demographic and comorbidity data that are typically available within health systems' electronic health records. In addition, the tool appears to be responsive to changes in the patient population's demographic profiles when estimating the expected hypertension prevalence. For example, although the tool was established using data that are reflective of the general US population, when data from the pooled cohort that had a higher hypertension and comorbidity prevalence were included, the tool was responsive enough to provide a clinically accurate estimate of those cohorts' hypertension prevalence. In addition, the tool incorporates comorbidity status, which was shown to be an important predictor of hypertension prevalence. Therefore, it can be used among populations with varying levels of comorbidity prevalence, including within specialty clinics (eg, endocrinology and cardiology) that often see patients with multiple health issues. Finally, flexibility has been built into the tool to accommodate health systems with limited access to the requested data elements. First, a race/ethnicity category of "Missing" was added to the standard version of the tool to accommodate health systems that are unable to report their data by race/ethnicity or who may have some patients who lack a race/ethnicity classification. Second, we developed a modified version of the tool for users who are unable to provide the comorbidity status of their patient population. The modified version applies NHANES-estimated comorbidity prevalence estimates to the sex-, age-, and race/ethnicity-specific values supplied by the user (e-Table I) to calculate the number of patients expected to fall into each comorbidity strata. These values are then applied to the standard version of the tool to calculate the health system's expected hypertension prevalence. We found that the modified version of the tool had similar external validity compared with the standard version among our randomly selected pooled cohort samples (e-Table II). However, the predictive ability of the modified tool is likely diminished if used among patient populations that have age-, sex-, and race/ethnicity-stratified comorbidity prevalence that differs considerably from the general US population. Therefore, users need to consider which version is most appropriate to apply to their patient population.

LIMITATIONS

There are potential limitations to the methods used to develop and validate the Estimator Tool. First, NHANES surveys only the noninstitutionalized US population and does not include those on active duty with the military or persons residing in nursing homes and other institutions; therefore, there may be some limitations to the generalizability of the findings. Second, 14 years of data were used to calculate the stratum-specific prevalence estimates; however, because consistent trends in hypertension prevalence occurred during this time and there were no observed changes in the association between the tool elements and hypertension risk, use of this historical data should still be able to accurately and precisely predict current hypertension prevalence estimates. Third, due to data availability, results for Mexican Americans were used to represent all Hispanics during 1999 to 2006. However, no change occurred among Hispanics' hypertension prevalence during the entire period 1999 to 2012 (Table IV); therefore, this change in categorization likely did not affect the overall findings. Fourth, NHANES estimates calculated for those aged 75 years and older are applied to health systems' data for patients aged 75 to 85 years. While this may slightly overestimate the hypertension prevalence in this age group, it makes the tool more functional for health systems as they are often asked to report on their hypertension management outcomes for only those

adults aged 18 to 85 years, such as reporting on measures related to the National Quality Forum's Controlling High Blood Pressure 0018 measure.[30] Fifth, modifications were made to the definitions used among the external datasets used for validation to most closely align with the definitions used among the NHANES participants, potentially allowing for misclassification. Sixth, while the Estimator Tool includes the strongest predictors of hypertension prevalence according to our NHANES model, these factors and other factors not included in the tool may affect hypertension prevalence differently across health systems. Moreover, we assume users of the tool have adequately identified and counted the number of people with comorbidities within their patient population, which may not be accurate. Therefore, the tool's accuracy in estimating hypertension prevalence will likely vary across users.

In addition, there was variation in how the datasets used to develop and validate the tool collected their BP measurements—either via HgS and auscultatory technique or AOD—and summarized their average BP values, which may limit the generalizability of the findings. While HgS devices are still currently used in some clinical practices to collect BP, use of AODs is now common practice, mainly to eliminate potential exposure to mercury by patients and staff.[31–33] However, AODs cannot exactly reproduce HgS readings and subsequent BP classifications, because each device type uses different approaches to obtain BP readings.[34,35] In addition, studies have noted differences in BP values and hypertension classification when results are compared using different AODs.[36] Despite this limitation, use of data from studies that collected and summarize BPs using different devices and methods allowed for a "real-world" assessment of how the Estimator Tool may be used by health systems. There are several other factors that may affect the tool user's results, including the time and frequency of BP measurement, technical issues, and patient-specific factors.[37–40] Technical guidelines on how to obtain BP accurately regardless of device used are available at http://www.measureuppressuredown.com/HCProf/toolkit.pdf.

Another key component in accurately estimating a population's hypertension prevalence is that a common hypertension definition is used. Most notably, a formal hypertension diagnosis is recommended to rely "on the average of two or more properly measured, seated BP readings on each of two or more office visits," conditions that cannot be completely met during the one NHANES visit[8]; therefore, the BP measure–based criteria used here may overestimate hypertension prevalence and the prevalence of undiagnosed hypertension. While this potential limitation likely did not affect the results of the validation assessment, as the external studies used for validation also collected BP at only one visit, it may affect the results obtained by health systems who use the tool as they likely require more than one visit to diagnose hypertension. In addition, the debate continues

over what population-level thresholds should be used to identify BP treatment goals.[41] The model supporting this tool uses the thresholds recommended for the general population by the Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure (JNC 7), as these recommendations remain endorsed by organizations including the American College of Cardiology and American Heart Association and the National Institutes of Health.[8] Further, they align with *Healthy People 2020* measures and NHANES follows the JNC 7 guidelines to obtain and classify BP measures. If health systems are following other guidance, eg, the thresholds recommended by James and coworkers,[42] the hypertension prevalence estimates of the Estimator Tool may not be directly comparable to their measured hypertension prevalence, especially among health systems with large elderly populations.[43] Moreover, health systems may use slightly different clinical and/or administrative definitions for the comorbidities included in the Estimator Tool. The clinical definitions outlined in e-Figure 1 follow the most current national recommendations and align with the definitions applied to the NHANES participants to develop this tool. Finally, while we obtained informal input on the usability of the tool from a diverse collection of Million Hearts partners that helped inform its development, including adding modified versions to assist lower-resourced clinics, we did not formally evaluate the usability of the tool across a broad array of health systems. Therefore, there may be some unforeseen limitations in the tool's usefulness among certain types of health systems, especially ones without a fully operational electronic health record system.

CONCLUSIONS

Many steps are necessary to optimally manage hypertension among a patient population. Identification of all of the patients with hypertension is one of the important first steps in this process. The Estimator Tool described here appears to be a clinically useful instrument that can be used to compare reported vs expected hypertension prevalence in health systems with diverse patient demographic and comorbidity profiles. Improvements in the identification of patients with hypertension followed by the use of evidence-based strategies to effectively manage their BP should lead to better BP control and decrease the number of heart attack, stroke, and other negative CVD events.

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Supporting Information
Additional Supporting Information may be found in the online version of this article:

e-Figure 1. Clinical definitions that health systems are encouraged to use to best align with currently endorsed guidelines and the methods used to develop the Hypertension Prevalence Estimator Tool.

e-Table I. Comorbidity prevalence, by sex, age, and race-ethnicity (National Health and Nutrition Examination Survey, 2005–2012).

e-Table II. External validity testing results for the modified Hypertension Prevalence Estimator Tool that does not include comorbidity status, by random sample size.