JAMA Network Open

Original Investigation | Geriatrics

Validation of a Health System Measure to Capture Intensive Medication Treatment of Hypertension in the Veterans Health Administration

Lillian Min, MD, MSHS; Jin-Kyung Ha, PhD; Timothy P. Hofer, MD, MSc; Jeremy Sussman, MD, MS; Kenneth Langa, MD, PhD; William C. Cushman, MD; Mary Tinetti, MD; Hyungjin Myra Kim, ScD; Matthew L. Maciejewski, PhD; Leah Gillon, MSW; Angela Larkin, BA; Chiao-Li Chan, MSW; Eve Kerr, MD, MPH

Abstract

IMPORTANCE Blood pressure (BP) targets are the main measure of high-quality hypertension care in health systems. However, BP alone does not reflect intensity of pharmacological treatment, which should be carefully managed in older patients.

OBJECTIVES To develop and validate an electronic health record (EHR) data-only algorithm using pharmacy and BP data to capture intensive hypertension care (IHC), defined as 3 or more BP medications and BP less than 120 mm Hg, and to identify conditions associated with greater IHC, either through greater algorithm false-positive IHC, or by contributing clinically to delivering more IHC.

DESIGN, SETTING, AND PARTICIPANTS This cross-sectional study was conducted among 319 randomly selected patients aged 65 years or older receiving IHC from the Veterans Health Administration (VHA) from July 1, 2011, to June 30, 2013. Data were collected from a total of 3625 primary care visits. Data were analyzed from January 2017 to March 2020.

EXPOSURES Calibration and measurement of the algorithm for IHC (algorithm IHC).

MAIN OUTCOMES AND MEASURES For each primary care visit, the reference standard, clinical IHC, was determined by detailed review of free-text clinical notes. The correlation in BP medication count between the EHR-only algorithm vs the reference standard and the sensitivity and specificity of the algorithm IHC were calculated. In addition, presence vs absence of contributing conditions acting in combination with hypertension management were measured to examine incidence of IHC associated with contributing conditions, including an acute condition that lowered BP (eg, dehydration), another condition requiring a BP target lower than the standard 140 mm Hg (eg, diabetes), or the patient needing a BP-lowering medication for a nonhypertension condition (eg, β-blocker for atrial fibrillation) resulting in low BP.

RESULTS Among 319 patients with 3625 visits (mean [SD] age, 75.6 [7.2] years; 3592 [99.1%] men), 911 visits (25.1%) had clinical IHC by the reference standard. The algorithm for determining medication count was highly correlated with the reference standard (r = 0.84). Sensitivity of detecting clinical IHC was 92.2% (95% CI, 89.3%-95.1%), and specificity was 97.2% (95% CI, 96.1%-98.3%), suggesting that clinical IHC can be identified from routinely collected data. Only 75 visits (2.1%) were algorithm IHC false positives, 55 visits (1.5%) involved IHC with contributing conditions, and 125 visits (3.5%) involved either false-positive or IHC with contributing conditions. Among select contributing conditions, congestive heart failure (37 patients [5.2%]) was most associated with a prespecified combined false-positive or IHC with contributing conditions rate higher than 5%.

(continued)

Key Points

Question Can health system data be used to accurately detect patients receiving intensive hypertension care with multiple blood pressure medications?

Findings This cross-sectional study used data from 319 patients with 3625 visits to develop an algorithm based on clinically measured blood pressure and pharmacy fills to detect intensive hypertension care delivered at any visit. Using electronic health record review of clinical notes as the reference standard to detect patients aged 65 years or older receiving 3 or more medications with systolic blood pressure of less than 120 mm Hg, the algorithm had a sensitivity of 92% and a specificity of 97%.

Meaning The findings of this study suggest that this algorithm could provide a resource for health care systems to measure high-intensity care for quality comparison or as a research tool.

+ Supplemental content

Author affiliations and article information are listed at the end of this article.

Abstract (continued)

CONCLUSIONS AND RELEVANCE These findings suggest that health system data can be used reliably to estimate IHC.

JAMA Network Open. 2020;3(7):e205417. doi:10.1001/jamanetworkopen.2020.5417

Introduction

Lower blood pressure (BP) and the intensive treatment with BP medications required to achieve it prevent strokes and death.[1-5] However, if achieving low BP requires multiple medicines, this could increase adverse effects and treatment burden. The current system of performance measures is designed to increase BP control, but it does not discourage intensive treatment that far exceeds the target (eg, by >20 mm Hg). In addition, BP declines naturally before death,[6,7] and BP control may be less beneficial among adults who are frail.[8] Therefore, further research is needed to support more clinically nuanced care for older adults who might not need such intensive hypertension care (IHC). However, before such research can be conducted in health systems, the first step is to determine whether IHC using multiple BP medications can be identified using health system data.

We have previously described approaches to assess BP level and medication treatment simultaneously from extractable electronic health record (EHR) data fields to improve large-scale health system efforts to achieve appropriate BP treatment.[9-12] However, there are reasons the EHR measure could be misleading about the actual care provided. A patient may fill a medication but later discontinue it owing to adverse effects, therefore using fewer medications than the pharmacy data would suggest.

We conducted this cross-sectional study to develop and validate the accuracy of an electronic measure of IHC for older patients in the Veterans Health Administration (VHA). In addition, we sought to understand which comorbid conditions, in combination with hypertension treatment, could potentially contribute synergistically to the delivery of IHC (eg, by increasing measurement error or because their treatment also requires BP medication treatment). The results could allow patients with those conditions to be analyzed separately or excluded from future quality improvement initiatives or health outcomes research.

Methods

This cross-sectional observational study was approved by the Department of Veterans Affairs (VA) institutional review board and Centers for Medicare & Medicaid Service data were provided by VA Health Services Research and Development Service, VA Information Resource Center. A waiver of informed consent was granted because the VHA dataset is large, and obtaining informed consent was considered not feasible for this study, per VA policy. This study is reported following the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

Data

We used 2009 through 2013 national VA Clinical Data Warehouse data, including all outpatient clinical encounters, vital signs, diagnoses, pharmacy records, and a file of non-VHA medications. We also linked 2011 to 2013 Medicare Part D drug claims to Clinical Data Warehouse data.

Sample

We identified a cohort of older patients (ie, age ≥65 years) with hypertension receiving VHA primary care during a 2-year period from July 1, 2011, to June 30, 2013. Eligibility was determined as having at least 1 hypertension (*International Classification of Diseases, Ninth Revision* [*ICD-9*] code 401.x[13])

diagnosis and an established primary care relationship (ie, ≥2 primary care visits in 2009-2011 with ≥1 of those visits in 2009 to 2010).

The unit of analysis was each eligible visit with physicians, nurses, advanced practice clinicians, pharmacists, or social workers in primary care (ie, family medicine, general or internal medicine, geriatrics, or mental health primary care), or specialty care clinicians who manage hypertension (ie, nephrologists, endocrinologists, cardiologists, and neurology outpatient nonemergency care clinicians) (eTable 1 in the Supplement). We defined eligible visits as days when BP measurements occurred on the same day as eligible services. We excluded visits occurring on a day that included nursing home or hospital care. eTable 2 in the Supplement provides code for constructing the measures.

To enhance our sample with a greater opportunity to study variations in IHC than in a general VHA sample, we used a preliminary algorithm (ie, prior to calibration) of IHC to identify patients with a continuous period of IHC[12]: systolic BP less than 120 mm Hg on at least 2 consecutive primary care visits, with both visits preceded by VHA BP medication fills of at least 3 different classes (any dose) within 100 days. Out of 1 260 150 older VHA patients with hypertension, the 60 899 veterans (4.8%) meeting these criteria had a mean (SD) of 12.5 (8.8) visits during the study period. Of 13 923 patients who entered the study period with prevalent IHC, only 1617 patients (11.6%) continued to have uninterrupted IHC for the rest of the study period. The overall mixture of visits was balanced between 79 704 episodes of contiguous IHC and 55 539 isolated IHC visits. From this sampling frame, we randomly selected 420 patients for further study (**Figure 1**).

Overview of Study Design

We first developed an algorithm to measure IHC using EHR extractable data fields only as the test. Then we reviewed the text-based clinical notes for documented BP medications, BP, and the clinical care provided (hereafter, the *reference standard).* Last, we measured the accuracy of the IHC EHR data algorithm against the reference standard.

Algorithm Development Using Pharmacy and BP EHR Data Only

To calibrate the medication algorithm, we structured the EHR data as a longitudinal series of BP medication fill events (from VHA data only) before and after each outpatient visit (**Figure 2**). Medications that reduced BP were organized into classes: (1) angiotensin agents as a single class containing both angiotensin-converting enzyme inhibitors (ACEIs) and angiotensin receptor blockers, (2) calcium channel blockers, (3) thiazide, (4) potassium-sparing diuretics, (5) β-blockers, (6) centrally acting α-agonists, (7) other vasodilators, and (8) direct renin blockers (eTable 3 in the Supplement). Fills of different medications within a class would be considered a switch between the medications rather than an additional medication.

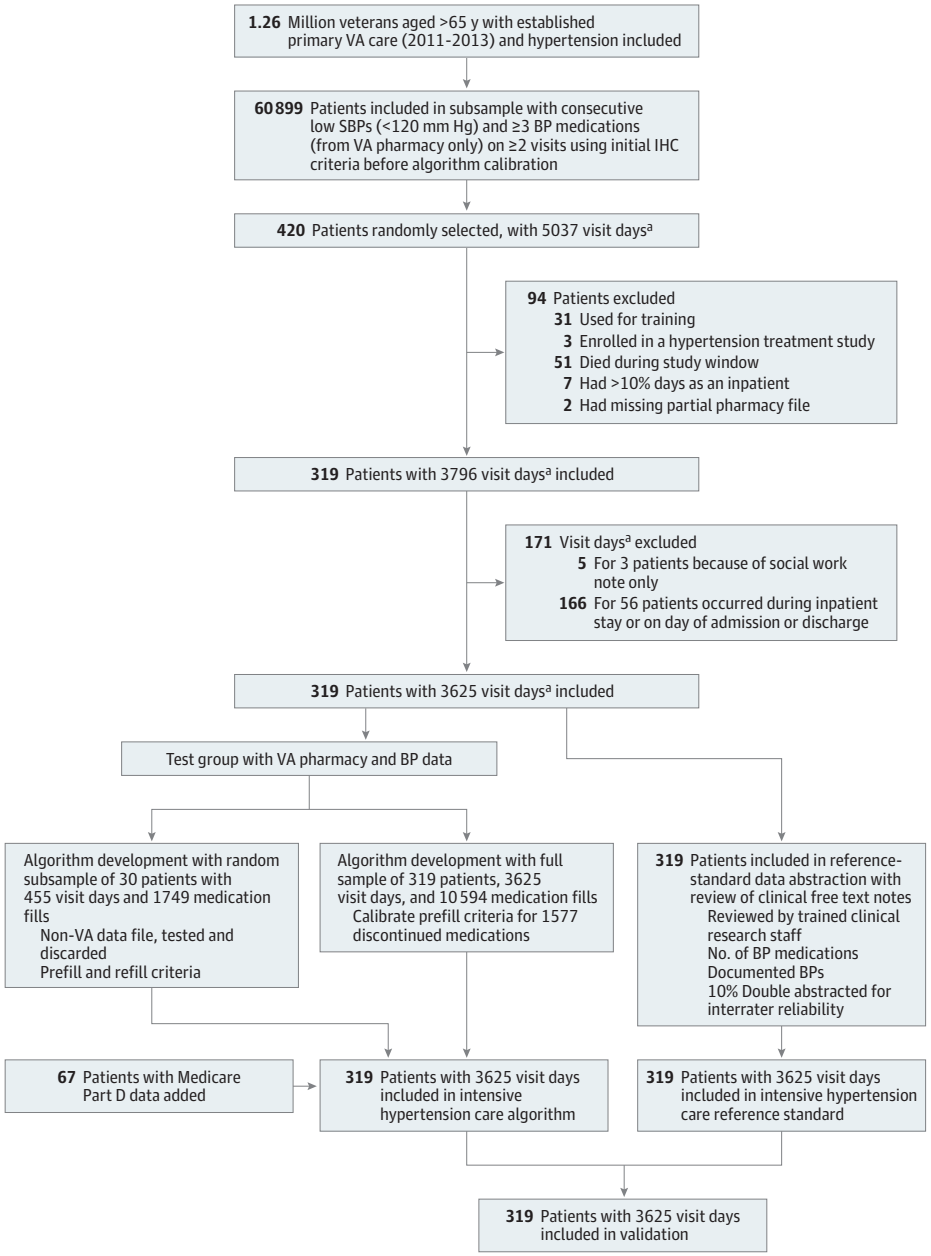
At each visit, we considered whether or not a patient was receiving a BP medication class using the pharmacy fill data prior to (ie, the prefill) and after each visit (ie, the refill). First, we considered continuously refilled BP medications. A prefill and a refill in the same class (Figure 2), regardless of the dose, was considered a match. For example, if patient had a lisinopril prefill, then a subsequent losartan fill (representing a switch within class) would be considered as the matched refill. We calibrated the algorithm on a subsample of 30 patients who had 455 visits and 1749 medication fill events. We first varied the criteria for days between the prefill and the eligible visit (ie, the look-back period) between 120 and 365 days to assess changes in false positives (positive algorithm test but the reference standard determined nonuse) and false negatives (negative algorithm test but the reference standard documented use). Second, we similarly varied the refill criteria. We allowed for time greater than the typical 90-day supply to bridge over a refill at a non-VHA pharmacy or verbal instructions to decrease the dose (eg, pill-splitting, which would increase the effective supply).

Next, we developed criteria for discontinued medications. If we found a medication with a prefill but no refill, we considered the medication to be potentially discontinued (ie, not active on the visit day). For each medication, we calculated time elapsed since the prefill date divided by number

of supplied days, resulting in a percentage of days' supply elapsed by the visit day (range, 0% to ≥100%). For example, if the prefill was for a 90-day supply and the visit was 30 days since the fill, then 33% of supply days were elapsed. We then calibrated the most accurate threshold in percentage of days' supply elapsed. We calibrated these thresholds separately depending on whether the potentially discontinued medication was chronic (defined as prefill with a prior fill within the past year) or new. Compared with continued medications, fewer medications were discontinued, so we used the entire analytic sample of 3625 visits to calibrate the discontinuation algorithm.

After algorithm calibration, we considered pharmacy data from 2 additional sources. First, we considered the non-VHA medication file maintained voluntarily by VHA clinicians. Despite reducing false-negative rate by 7.5%, this data source worsened false positives by 45.0%. Therefore, we dropped this data source from further analysis. Second, 67 patients (21.0%) also used Medicare Part

Figure 1. Algorithm Development and Validation Strategy



[a] Eligible visit days were defined as days when blood pressure (BP) measurements occurred on the same day as eligible services. Visits occurring on a day that included nursing home or hospital care were excluded.

IHC indicates intensive hypertension treatment; and VA, Department of Veterans Affair.

D. The proportion of visits with at least 3 medications increased from 63.8% in the VHA-only pharmacy data to 67.8% after adding Medicare D data, so we retained Part D data for subsequent analysis.

EHR Review

Trained EHR abstractors (including L.G. and A.L.) reviewed free-text clinical notes to obtain key elements for comparison with EHR and pharmacy data. First, abstractors added documented BP data on eligible visits not already captured in the EHR data (eg, if manually rechecked during the visit or from a home BP log on the same day as the visit). Next, to determine the daily BP medications, reviewers read all eligible visit notes as well as interval notes between eligible visits (eg, telephone notes, emergency visits, hospital discharge summaries), including scanned non-VHA notes.

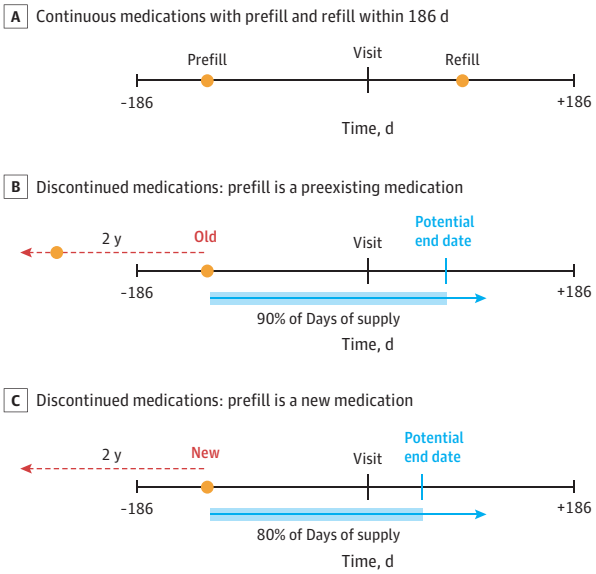
Reference Standard Review of Visits for Contributing Conditions

We reviewed the clinical notes for 3 types of contributing conditions, circumstances in which a condition may have been associated with IHC at the visit (ie, acting in combination synergistically with hypertension treatment). The 3 IHC with contributing conditions situations were (1) an acute condition spuriously lowering BP (eg, dehydration), (2) another chronic condition requiring a BP target lower than 140 mm Hg (eg, diabetes), and (3) a need to take a BP-lowering medication for a nonhypertension chronic condition (eg, a β-blocker for heart rate control in atrial fibrillation) that was documented as causing low BP. More than 1 contributing condition could be coded for any IHC with contributing conditions visit. A total of 10% of EHRs were abstracted by 2 coders (L.G. and A.L.) for interrater reliability in presence vs absence of each class of BP medications and any contributing conditions vs no contributing conditions (pooled κ = 0.92).

Statistical Analysis

We used manual review of clinical notes as the reference standard and the medication algorithm as the test to count the number of medications at each visit. If more than 1 systolic BP was measured in a visit, we calculated the systolic BP as the mean to reflect underlying true BP. If the clinical notes documented additional systolic BPs (eg, rechecked by the clinician or noted on a home BP log), then it was possible for the reference standard to differ from the EHR-only systolic BP.

Figure 2. Final BP Medication Identification Algorithm



We calculated (1) agreement as κ between the EHR and reference standard for the presence vs absence of each BP medication class and (2) the correlation in total number of medications at each visit. Next, we classified each visit as representing IHC or not (defined as ≥3 BP medication classes and mean systolic BP <120 mm Hg) by the reference standard and by the final developed algorithm. We calculated sensitivity, specificity, positive predictive value, and negative predictive value of the algorithm IHC. All calculations adjusted SEs by clustering of visits within patient. Next, we added the false-positive rate with the IHC with contributing conditions rate to estimate the percentage of visits that the algorithm IHC potentially overestimated hypertension care intensity. We calculated this summary measure in the overall sample and by chronic condition subsamples (ie, diabetes, coronary heart disease, cardiovascular disease, arrhythmia, heart failure [HF], chronic kidney disease, psychiatric conditions, and benign prostatic hypertrophy). We set a 5% rate as the clinically significant proportion of false-positives (either due to a data error or because a comorbidity was the reason for IHC). We hypothesized that IHC would be more likely to be overestimated (owing to false-positive and IHC with contributing conditions) for conditions also treated with BP-lowering medications (eg, HF). The chronic conditions were determined by any coded visit diagnoses during the observation window, and all visits for that patient were considered associated with those conditions.

Data were analyzed using SAS version 9.4 (SAS Institute) and Stata version 14 (StataCorp) statistical software. Data analysis was conducted from January 2017 to March 2020.

Results

Of 420 randomly sampled patients, we used 31 EHRs to train EHR abstractors. We discarded these EHRs. Of 389 remaining patients, we excluded 58 patients who died during the observation period, 7 who spent 10% or more of the study time in inpatient or nursing home care, 3 patients enrolled in a hypertension treatment trial, and 2 patients for missing Medicare pharmacy files (Figure 1). The analytic sample of 3625 visits for 319 remaining patients (mean [SD], 11.4 [8.3] visits per patient) included 3582 visits (99.1%) from men, with a mean (SD) age of 75.6 (7.2) years. The prevalence of other chronic conditions was comparable to the general older VHA population,[14] including 1090 visits (30.1%) from patients with diabetes, 706 visits (19.5%) from patients with congestive HF, and 1042 visits (28.7%) from patients with coronary artery disease (**Table 1**). The reference standard mean (SD) count of BP medications was 2.58 (0.96). The mean (SD) systolic BP was 121.8 (16.4) mm Hg. Among 3625 total visits, 911 visits (25.1%) met criteria for IHC by the reference standard review (Table 1).

Algorithm Development to Determine Active Medication Use on Each Visit Day

For calibration of continuous refills in the subset of 30 patients with 455 visits, we found a steady decrease in false negatives when broadening the lookback window from 14.2% at 120 days to 10.8% at 365 days. The false-positive rate was low and varied little when the look-back window changed, starting at 1.2% at 120 days, increasing to 1.3% at 136 days, but increasing to 1.3% between 180 and 200 days. We set our prefill and refill at 186 days (31 days × 6 months).

On the full sample, 3625 visits were associated with 10 594 medications with valid prefills within 186 days. After 9017 prefilled medications (85.1%) were matched with a valid refill, we calibrated the remaining prefilled medications without a valid refill (1577 medications [14.9%]) as potentially discontinued medications (eFigure in the Supplement). The false-positive and false-negative rates were optimized if the visit date occurred before 80% of the days' supply elapsed for discontinuation of new medications and before 90% of the day's supply elapsed for old medications. The discontinuation criteria restored 511 true-positive medications (4.8%), compared with an algorithm that required medications to be refilled to be counted. These analyses resulted in the final algorithm (Figure 2).

Validating Algorithm to Identify IHC

In the analytic sample of 319 patients, the count of BP medications in the algorithm (mean [SD], 2.59 [0.98]; range 0-6) vs the reference standard (mean [SD], 2.58 [0.96]; range 0-6) was highly correlated (r = 0.84 [95% CI, 0.79-0.89]). The correlation was also high for the algorithm applied to VHA-only (ie, without Medicare Part D) pharmacy data (r = 0.84 [95% CI, 0.83-0.85]). The most common medications were ACEIs or angiotensin receptor blockers (2870 visits [79.2%]) and β-blockers (2899 visits [80.0%]). The agreement for each class ranged from κ = 0.83 (β-blocker and ACEI or angiotensin receptor blockers) to κ = 0.96 (potassium-sparing diuretics).

We found positive algorithm IHC at 915 visits (25.3%) vs the reference standard at 911 visits (25.1%). The sensitivity was 92.2% (95% CI, 89.3%-95.1%), specificity was 97.2% (95% CI, 96.1%-98.3%), positive predictive value was 91.8% (95% CI, 88.5%-95.1%), and negative predictive

Table 1. Characteristics of Visits Included in the Analytic Sample

Variable	No. (%) (N = 3625 visits)
Age, mean (SD) [range], y	75.6 (7.2) [65-96]
Men	3592 (99.1)
Low BP[a]	1721 (47.5)
Using ≥3 medications[b]	1895 (52.2)
Low BP and ≥3 BP medications[a,b]	911 (25.1)
Chronic condition	
Diabetes	1090 (30.1)
Atherosclerotic heart, cerebrovascular, or peripheral vascular disease	1042 (28.7)
Arrhythmia	738 (20.4)
Any heart failure or valve disease	706 (19.5)
Kidney disease	372 (10.3)
Psychiatric disease	341 (9.4)
Benign prostatic hypertrophy	261 (7.2)
Medication class [c]	
β-blocker	2913 (80.4)
Angiotensin-converting enzyme inhibitor or angiotensin receptor blocker	2856 (78.8)
Calcium channel blocker	1524 (42.0)
Thiazide diuretic	1195 (33.0)
Potassium sparing diuretic	584 (16.1)
Vasodilator	140 (3.9)
Centrally acting α-blocker	117 (3.2)
Direct renin blocker	24 (0.7)

Abbreviation: BP, blood pressure.

[a] Defined as less than 120 mm Hg as based on the mean of all BPs documented in the clinical notes.

[b] Determined by electronic health record review.

[c] Includes any medications used during the study period.

Table 2. Acute and Chronic Conditions Contributing to IHC

Conditions contributing to IHC	No. (% of total) (N = 3625 visits)	
	Contributing condition identified in medical record review	Algorithm-positive IHC visits with contributing condition
Acute cause of low BP	31 (0.9)	16 (0.4)
Intensified BP goal to <140 mm Hg to treat a comorbid condition	97 (2.7)	16 (0.4)
Low BP caused by a medication necessary to treat another condition	52 (1.4)	24 (0.7)
Any contributing condition	174 (4.8)	55 (1.5)

Abbreviations: BP, blood pressure; IHC, intensive hypertension care.

value was 97.4% (95% CI, 96.4%-98.4%), suggesting that IHC could be validly identified from routinely collected data. Of 3625 visits, 75 visits (2.1%) were false positives due to errors in EHR data.

Conditions Contributing to IHC

A positive algorithm IHC visit could also have a contributing condition. Of 3625 visits, the reference standard review identified 174 visits (4.8%) with a potential contributing condition, but only 55 visits (1.5%) were also algorithm IHC positives (**Table 2**), including 16 visits (0.4%) with an acute contributing condition, 16 visits (0.4%) with an intentionally low BP target owing to a contributing condition, and 24 visits (0.7%) with a treatment tradeoff due to treatment of the contributing condition.

There were 125 visits (3.5%) that were potentially overestimated owing to false positive or IHC with contributing condition (**Table 3**). Of comorbid conditions, only 37 patients with congestive HF (5.2%) had a total potential combined rate of either false positive or IHC with contributing conditions that exceeded 5%. The next highest conditions with overestimated IHC were prostate disease (13 patients [5.0%]) and psychiatric condition (14 patients [4.1%]).

Discussion

In this cross-sectional study using large national health care system data, we developed a method to capture IHC, defined as 3 or more BP medications with systolic BP less than 120 mm Hg. Our calibrated algorithm for IHC had sensitivity of 92.2% and specificity of 97.2%, with an overall low total rate of false positives (2.1% of all visits).

We were also able to test whether certain comorbid conditions contributed to false-positive IHC or situations in which a nonhypertension condition contributed or mixed effects with hypertension treatment to result in clinical IHC. Patients with congestive HF were the most likely to have visits of either type of overestimation, thus future applications of IHC may need to stratify by patient

Table 3. Top 7 Chronic Condition Categories Associated With False-Positive Algorithm IHC and Contributing Conditions to IHC

		Visits, No. (%)			
			Potentially overestimated IHC		
Diagnoses[a]	Total visits	Algorithm IHC	False positives[b]	Visit with contributing condition to IHC	Total
All patients	3625	915 (25.2)	75 (2.1)	55 (1.5)	125 (3.5)
Diabetes	1090	271 (24.9)	14 (1.3)	19 (1.7)	33 (3.0)
CAD, CVD, or PAD	1042	234 (24.7)	12 (1.2)	21 (2.0)	31 (3.0)
Arrhythmia[c]	738	182 (24)	8 (1.1)	21 (2.9)	27 (3.7)
CHF or any valve disease	706	219 (31)	14 (2.0)	26 (2.7)	37 (5.2)
Chronic kidney disease	372	81 (21.8)	4 (1.1)	0	4 (1.1)
Psychiatric condition[d]	341	97 (28.5)	6 (1.8)	8 (2.4)	14 (4.1)
BPH	261	57 (21.8)	4 (1.5)	9 (3.5)	13 (5.0)

Abbreviations: BPH, benign prostatic hypertrophy; CAD, coronary artery disease; CHF, congestive heart failure (includes low and preserved ejection fraction and non-specific type); CVD, cerebrovascular disease; IHC, intensive hypertension treatment; PAD, peripheral arterial disease.

[a] Condition categories were assigned to patients based on any outpatient visits with *International Classification of Diseases, Ninth Revision (ICD-9)* diagnoses during the study period. All visits for the patient were assigned to that condition. Other conditions tested but not displayed due to number of visits fewer than 100 and IHC visits were also fewer than 10: eye problem, fall or gait impairment, failure to thrive, neurologic condition, orthostatic hypertension, and venous or lower extremity edema.

[b] Occurring when using discrete blood pressure and pharmacy fill data from the Veterans Health Administration electronic health record, compared to the reference standard chart review.

[c] Includes atrial fibrillation and flutter.

[d] Includes depression, bipolar disease, and posttraumatic stress disorder.

condition or remove patients with congestive HF. We may have underestimated the rate of less prevalent conditions in IHC with contributing conditions owing to small sample size. The condition with the second highest prevalence of overestimation, benign prostatic hypertrophy, may be specific to the VHA, owing to wide use of terazosin in the VHA serving as a double-duty drug for hypertension and urinary retention. The third ranked condition, psychiatric condition, may have been due to dual use of clonidine for posttraumatic stress disorder.

This study builds on methods previously developed to use health system data to measure the adequacy of clinical action, not only by measuring the percentage of patients with BP below a certain threshold, but also capturing the intensity of BP medications prescribed.[12] By integrating BP values and medications, we gain a more comprehensive view of the care provided to patients by a clinician or a health system than by using BP alone. Using only BP as the target (eg, BP <140/90 mm Hg, the current performance measure in the VHA and by health insurances) is a far simpler computation. By capturing medication intensity, it is possible to capture more clinical nuance: from intense treatment (low BP and multiple medications), to mild undertreatment (moderate hypertension on treatment), to severe undertreatment (no medications despite high BP). This method paves the way beyond dichotomous BP targets for future research based on intensity of care.

Medication data combined with BP yields greater understanding of systems-based management than BP alone. We have found previously that intensively treated BP for patients with diabetes is rarely deintensified, with little effect by advanced age or mortality risk.[15] Research by others has captured IHC accurately by computerized administration records in more acute settings: intensifying hypertension regimens on hospital discharge worsens clinical outcomes of older adults,[16] and intensely treated patients in postacute nursing homes with history of falls are less likely to fall again after deintensification.[17] This study now broadens our understanding of administrative data accuracy for capturing IHC in the outpatient setting. This method will be important in coming years after the Systolic Blood Pressure Intervention Trial (SPRINT)[2] has redefined what we consider to be beneficial yet high-intensity treatment. How we defined IHC (ie, BP <120 mm Hg and using ≥3 BP medications) is consistent with the SPRINT intervention, in which the goal was to attain a target BP of less than 120 mm Hg by increasing medications prescribed. We note here that the period of time covered by these analyses preceded publication of the SPRINT results, during a time when the systolic BP goal within the VHA was less than 140 mm Hg. These patients may have been treated intensively above and beyond the VHA goals at the time, but in the post-SPRINT era, this degree of intensity may be more commonly attained for many older patients.

Strengths and Limitations

This study has some strengths. The main strength was its national patient representation and its use of multiple sources of data. The algorithm was calibrated using only VHA pharmacy data. The inclusion of Medicare Part D data added to the complete picture; however, those data were not critical to the accuracy of the algorithm. Therefore, our results would be applicable to health systems or insurance plan populations for whom most pharmacy data are obtainable. Second, our method calibrated the algorithm to capture IHC at any patient visit, therefore allowing flexibility for future outcomes studies to study the combination of visits needed to construct measures of short- or long-term exposure to IHC. For example, one could study patients with year-over-year change in IHC (by comparing last visit IHC of each year) or select patients with consecutive visits of IHC to identify those with consistent long-term IHC.

There are several limitations that must be acknowledged. First, we had to ensure that our sample was intensively treated and had variability between visits to have an opportunity to test for the absence or presence of IHC. Therefore, we studied patients with generally intensive BP care, possibly resulting in a false-positive rate that is higher than in the rest of the VHA. Second, for a portion of our algorithm (ie, medications that were discontinued), we needed to use the entire data set for calibration then validated back using the same sample, therefore potentially overestimating the algorithm accuracy. Third, we were unable to distinguish patients with HF with reduced ejection

fraction, which we expect would be more likely than preserved ejection fraction to contribute to finding IHC with contributing conditions, because HF with reduced ejection fraction is appropriately treated with BP-lowering medications to achieve BP below usual hypertension goals. Fourth, our algorithm could not capture free samples of BP medications dispensed by non-VHA clinics and BP medications purchased at lower cost than VHA copayments (eg, $5 generic programs). Last, this older population was predominantly male; therefore, we could not test for sex differences in algorithm accuracy. An older cohort of women might be treated less aggressively for comorbid conditions,[18] potentially limiting our IHC with contributing conditions analysis among women.

Conclusions

This cross-sectional study's focus on medication counts is the first step in validating a high-intensity BP regimen, but there is still room for further research regarding dosing intensity. Current guidelines for comorbid conditions now recommend treatment with BP-lowering medications, such as low-dose ACEIs for renal protection in diabetes. Therefore, capturing total doses in addition to medications prescribed will reflect IHC with greater granularity in the context of guideline-consistent care.

We have developed and validated an algorithm to identify patients with IHC in health systems. This method could be used to compare IHC among clinicians or systems or to improve appropriateness of patient care.

ARTICLE INFORMATION

Accepted for Publication: March 17, 2020.

Published: July 30, 2020. doi:10.1001/jamanetworkopen.2020.5417

Corresponding Author: Lillian Min, MD, MSHS, Division of Geriatric and Palliative Medicine, Department of Internal Medicine, University of Michigan, 300 N Ingalls Bldg, Floor 9, Ann Arbor, MI 48109 (lmin@umich.edu).

Author Affiliations: VA Ann Arbor Medical Center, Geriatric Research, Education, and Clinical Center, Ann Arbor, Michigan (Min, Langa); Division of Geriatric and Palliative Medicine, Department of Internal Medicine, University of Michigan, Ann Arbor (Min, Ha, Chan); VA Center for Clinical Management Research, Health Services Research and Development Center of Innovation, Ann Arbor, Michigan (Min, Hofer, Sussman, Gillon, Larkin, Kerr); Institute of Healthcare Policy and Innovation, University of Michigan, Ann Arbor (Min, Hofer, Sussman, Langa, Kerr); Division of General Internal Medicine, Department of Internal Medicine, University of Michigan, Ann Arbor (Hofer, Sussman, Langa, Kerr); Institute for Social Research, University of Michigan, Ann Arbor (Langa); Preventive Medicine Section, Memphis VA Medical Center, Memphis, Tennessee (Cushman); Department of Preventive Medicine, University of Tennessee Health Science Center, Memphis (Cushman); Department of Medicine, Section of Geriatrics, Yale School of Medicine, New Haven, Connecticut (Tinetti); Consulting for Statistics, Computing and Analytics Research, University of Michigan, Ann Arbor (Kim); Department of Biostatistics, University of Michigan Medical School, Ann Arbor (Kim); Accelerate Discovery and Practice Transformation Center of Innovation, VA Health Care System, Durham, North Carolina (Maciejewski); Department of Population Health Sciences, Duke University, Durham, North Carolina (Maciejewski).

Author Contributions: Dr Min had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Concept and design: Min, Hofer, Cushman, Kim, Maciejewski.

Acquisition, analysis, or interpretation of data: Min, Ha, Hofer, Sussman, Langa, Tinetti, Kim, Gillon, Larkin, Chan, Kerr.

Drafting of the manuscript: Min, Ha, Hofer.

Critical revision of the manuscript for important intellectual content: Min, Sussman, Langa, Cushman, Tinetti, Kim, Maciejewski, Gillon, Larkin, Chan, Kerr.

Statistical analysis: Min, Ha, Sussman, Kim, Maciejewski, Chan.

Obtained funding: Min, Kim, Kerr.

Administrative, technical, or material support: Sussman, Maciejewski, Gillon, Larkin, Chan.

Supervision: Hofer.

Conflict of Interest Disclosures: Dr Hofer reported receiving grants from the Department of Veteran Affairs (VA) Health Services Research and Development Service (HSR&D) and National Heart, Lung, and Blood Institute during the conduct of the study. Dr Sussman reported receiving grants from the VA during the conduct of the study. Dr Langa reported grants from the National Institutes of Health (NIH) during the conduct of the study. Dr Cushman reported receiving grants from the NIH and NIA during the conduct of the study; and grants from Eli Lilly, personal fees from Sanofi, and consulting for Novartis outside the submitted work. Dr Maciejewski reported receiving grants from the VA HSR&D during the conduct of the study and owing stock in Amgen owing to his spouse's employment. Dr Kerr reported receiving grants from the VA HSR&D and NIA during the conduct of the study and personal fees from Bind Insurance outside the submitted work. No other disclosures were reported.

Funding/Support: This material is based on work supported by grant No. IIR 14-083 from the Department of Veterans Affairs, Veterans Health Administration, Office of Research and Development, Health Services Research and Development (VA HSRD) and grant No. R01 AG047178 from the National Institute on Aging. Dr Maciejewski received support from grant No. RCS 10-391 from the VA HSRD.

Role of the Funder/Sponsor: The funders had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

REFERENCES

1. Staessen JA, Gasowski J, Wang JG, et al. Risks of untreated and treated isolated systolic hypertension in the elderly: meta-analysis of outcome trials. *Lancet*. 2000;355(9207):865-872. doi:10.1016/S0140-6736(99)07330-4

2. Wright JT Jr, Williamson JD, Whelton PK, et al; SPRINT Research Group. A randomized trial of intensive versus standard blood-pressure control. *N Engl J Med*. 2015;373(22):2103-2116. doi:10.1056/NEJMoa1511939

3. Williamson JD, Supiano MA, Applegate WB, et al; SPRINT Research Group. Intensive vs standard blood pressure control and cardiovascular disease outcomes in adults aged ≥75 years: a randomized clinical trial. *JAMA*. 2016;315(24):2673-2682. doi:10.1001/jama.2016.7050

4. Gueyffier F, Bulpitt C, Boissel JP, et al; INDANA Group. Antihypertensive drugs in very old people: a subgroup meta-analysis of randomised controlled trials. *Lancet*. 1999;353(9155):793-796. doi:10.1016/S0140-6736(98)08127-6

5. Beckett NS, Peters R, Fletcher AE, et al; HYVET Study Group. Treatment of hypertension in patients 80 years of age or older. *N Engl J Med*. 2008;358(18):1887-1898. doi:10.1056/NEJMoa0801369

6. Rogers MA, Ward K, Gure TR, et al. Blood pressure trajectories prior to death in patients with diabetes. *Diabetes Care*. 2011;34(7):1534-1539. doi:10.2337/dc11-0441

7. Ravindrarajah R, Hazra NC, Hamada S, et al. Systolic blood pressure trajectory, frailty, and all-cause mortality >80 years of age: cohort study using electronic health records. *Circulation*. 2017;135(24):2357-2368. doi:10.1161/CIRCULATIONAHA.116.026687

8. Odden MC, Peralta CA, Haan MN, Covinsky KE. Rethinking the association of high blood pressure with mortality in elderly adults: the impact of frailty. *Arch Intern Med*. 2012;172(15):1162-1168. doi:10.1001/archinternmed.2012.2555

9. Hayward RA. All-or-nothing treatment targets make bad performance measures. *Am J Manag Care*. 2007;13(3):126-128.

10. Kerr EA, Smith DM, Hogan MM, et al. Comparing clinical automated, medical record, and hybrid data sources for diabetes quality measures. *Jt Comm J Qual Improv*. 2002;28(10):555-565. doi:10.1016/S1070-3241(02)28059-1

11. Kerr EA, Zikmund-Fisher BJ, Klamerus ML, Subramanian U, Hogan MM, Hofer TP. The role of clinical uncertainty in treatment decisions for diabetic patients with uncontrolled blood pressure. *Ann Intern Med*. 2008;148(10):717-727. doi:10.7326/0003-4819-148-10-200805200-00004

12. Kerr EA, Lucatorto MA, Holleman R, Hogan MM, Klamerus ML, Hofer TP; VA Diabetes Quality Enhancement Research Initiative (QUERI) Workgroup on Clinical Action Measures. Monitoring performance for blood pressure management among patients with diabetes mellitus: too much of a good thing? *Arch Intern Med*. 2012;172(12):938-945. doi:10.1001/archinternmed.2012.2253

13. World Health Organization. *International Classification of Diseases, Ninth Revision (ICD-9)*. World Health Organization; 1977.

14. Steinman MA, Lee SJ, John Boscardin W, et al. Patterns of multimorbidity in elderly veterans. *J Am Geriatr Soc*. 2012;60(10):1872-1880. doi:10.1111/j.1532-5415.2012.04158.x

15. Sussman JB, Kerr EA, Saini SD, et al. Rates of deintensification of blood pressure and glycemic medication treatment based on levels of control and life expectancy in older patients with diabetes mellitus. *JAMA Intern Med*. 2015;175(12):1942-1949. doi:10.1001/jamainternmed.2015.5110

16. Anderson TS, Jing B, Auerbach A, et al. Clinical outcomes after intensifying antihypertensive medication regimens among older adults at hospital discharge. *JAMA Intern Med*. 2019. doi:10.1001/jamainternmed.2019.3007

17. Song W, Intrator O, Lee S, Boockvar K. Antihypertensive drug deintensification and recurrent falls in long-term care. *Health Serv Res*. 2018;53(6):4066-4086. doi:10.1111/1475-6773.13074

18. Mehta PA, Cowie MR. Gender and heart failure: a population perspective. *Heart*. 2006;92(suppl 3):iii14-iii18. doi:10.1136/hrt.2005.070342

SUPPLEMENT.

eTable 1. Veterans Health Administration Stop Codes Used to Classify a Primary Care Visit or Specialty Visit

eTable 2. SAS Code for Applying Algorithm to Count Blood Pressure Medications in Health Care Administrative Data

eTable 3. Medication and Class

eFigure. Calibrating Discontinued Medication Algorithm