Impact of Computerized Decision Support on Blood Pressure Management and Control: A Randomized Controlled Trial

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BACKGROUND: We conducted a cluster randomized controlled trial to examine the effectiveness of computerized decision support (CDS) designed to improve hypertension care and outcomes in a racially diverse sample of primary care patients.

METHODS: We randomized 2,027 adult patients receiving hypertension care in 14 primary care practices to either 18 months of their physicians receiving CDS for each hypertensive patient or to usual care without computerized support for the control group. We assessed prescribing of guideline-recommended drug therapy and levels of blood pressure control for patients in each group and examined if the effects of the intervention differed by patients' race/ethnicity using interaction terms.

MEASUREMENTS AND MAIN RESULTS: Rates of blood pressure control were 42% at baseline and 46% at the outcome visit with no significant differences between groups. After adjustment for patients' demographic and clinical characteristics, number of prior visits, and levels of baseline blood pressure control, there were no differences between intervention groups in the odds of outcome blood pressure control. The use of CDS to providers significantly improved Joint National Committee (JNC) guideline adherent medication prescribing compared to usual care (7% versus 5%, $P < 0.001$); the effects of the intervention remained after multivariable adjustment (odds ratio [OR] 1.39 [CI, 1.13–1.72]) and the effects of the intervention did not differ by patients' race and ethnicity.

CONCLUSIONS: CDS improved appropriate medication prescribing with no improvement in disparities in care and overall blood pressure control. Future work focusing on improvement of these interventions and the study of other practical interventions to reduce disparities in hypertension-related outcomes is needed.

KEY WORDS: hypertension; race and ethnicity; implementation research; randomized trials.

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INTRODUCTION

Measuring and improving the quality of hypertension care has become a national priority in recent years. Prior studies have demonstrated substantial problems in the quality of hypertension treatment and low rates of blood pressure control, as well as racial and socioeconomic disparities.^{1–14} Hypertension is particularly burdensome among racial/ethnic minority groups^{7–14} and hypertension-related cardiovascular disease has been shown to be the greatest contributor to racial differences in mortality.¹²

Several reviews have emphasized the importance of designing pragmatic interventions to improve care and reduce disparities in outcomes of chronic diseases^{15–17}; one such intervention may be the use of computerized decision support (CDS). In a prior randomized trial, we found that CDS for diabetes and coronary artery disease care were effective for improving provider adherence with recommended processes of care.¹⁸ Other studies have also demonstrated that computer-based reminders are effective in improving measures of process of care, but intermediate clinical outcomes, such as blood pressure control, are rarely examined and when studied are frequently not improved.^{19–23}

We utilized a practical cluster randomized controlled trial²⁴ to examine the effectiveness of CDS, designed to remind physicians about hypertension treatment guidelines with the goals of: (1) improving levels of blood pressure control, (2) improving provider adherence with recommended drug therapy, and (3) reducing racial/ethnic disparities in hypertension care and outcomes.

METHODS

The trial period was from July 1, 2003 through February 1, 2005. The sample included 8 community-based and 6 hospital-based primary care practices affiliated with a large urban academic medical center; these practices were stratified by size and type (women's health versus general primary care and

community health center [CHC] versus non-CHC). We then randomized half of these clinics to have their physicians receive CDS for each hypertensive patient as an intervention and half to provide usual care without computerized decision support. In addition to our trial of CDS, 1 hospital-based clinic from each of the study arms was randomly selected to participate in a concurrent pilot trial examining the effectiveness of interval visits for hypertensive patients with a specialized nurse practitioner (NP) between regularly scheduled primary care appointments. Figure 1 illustrates the clinic assignment and patient selection used for the study.

We examined data obtained from the electronic medical record (EMR) of patients older than 20 years with a diagnosis

of hypertension to determine whether the use of CDS improved physician prescribing of guideline-recommended drug therapy and levels of blood pressure control and if the effects of this intervention differed by patient race/ethnicity. The Human Studies Committee at the Brigham and Women's Hospital approved the study protocol.

Study Sites and Patient Sample

We studied adult patients with at least 1 hypertension-related outpatient visit to 1 of the study clinics during the 1-year period before the beginning of the interventions. From these patients, we examined records of patients aged

* UC= Usual Care; CDS= Computerized Decision Support for all physicians within the practice; NP= Nurse Practitioner

Figure 1. Flow diagram of clinic randomization and nurse practitioner subject recruitment. We analyzed a total of 2,027 patients receiving care in clinics assigned to either computerized decision support (CDS) for all providers within the practice or no CDS. One clinic from each study arm was subsequently randomized to co-management with a nurse practitioner (NP) for hypertension patients, resulting in 1,048 patients who received usual care without NP co-management, 120 patients who received NP co-management whose provider did not receive CDS, 786 patients who did not receive NP co-management whose provider received CDS, and 73 patients who received NP co-management and whose provider received CDS.

>20 years, who had at least 2 hypertension-related outpatient visits to 1 of the participating practices during the intervention trial, and whose race/ethnicity was available (96%) in administrative data. All of the clinics involved in the study used EMR, including electronic prescribing of medications, for each patient during the study period. To identify hypertension-related visits, we reviewed the electronic medical record for all clinic visits with a primary or secondary diagnostic code of hypertension (HTN) (ICD-9 401–401.9, 405–405.99).

Evidence-based Guidelines

Using national guidelines or standards including the Health Plan Employer Data and Information Set (HEDIS), the sixth and seventh reports of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure (JNC VI and VII), and the American Heart Association/American College of Cardiology (AHA/ACC) 2001 guidelines for cardiovascular disease prevention, we developed racial and disease-specific (i.e., diabetes, congestive heart failure, coronary heart disease) algorithms for blood pressure treatment emphasizing the pharmacologic drug class recommended for each condition.^{1,6,25,26}

Computerized Decision Support Protocol

We used similar methods to our previously described study of electronic decision support.¹⁸ Each time that a clinician opened a patient’s chart, an algorithm was run within the EMR to determine whether the patient was receiving a medication in an antihypertensive drug class in accordance with JNC guidelines. The algorithm searched patients’ vital signs, problem lists, medication lists, and allergy lists within the electronic record. CDS was automatically generated for a patient based on a documentation of hypertension in the problem list, or an average of the patient’s 3 most recent documented blood pressure readings ≥140/90 for patients without an existing diagnosis of hypertension, and the patient not having any medications in the guideline-recommended drug class on their medication list. Patients with a listed allergy to a drug in the recommended class were not considered eligible to receive the recommended therapy. The reminders were extensively tested before implementation using dummy patients within the EMR.

Before the start of the intervention, participating physicians were sent a global e-mail notifying them of new hypertension-related reminders. Once the CDS was generated, all clinicians practicing within clinics randomized to CDS received the appropriate reminders. Reminders were displayed within the EMR on the main patient summary screen when the patient’s record was accessed; these reminders were suppressed for physicians practicing in clinics in the control arm. In addition to the electronic display, the reminders generated from the CDS could also be printed off onto a paper version generated using the same algorithms as the electronic reminders; these reminders could be printed on a patient summary page and were distributed to physicians at the beginning of a practice session. Table 1 demonstrates examples of the reminders generated by our CDS for physicians. Algorithms for each of the CDS rules and subsequent reminders are available in the Appendix figure.

Nurse Practitioner Protocol

During the pilot NP trial, patients reporting for routine hypertension care to a clinic assigned to the NP arm were called by study staff within 1 week of their most recent visit during the study period to explain the purpose of the NP and to obtain their verbal consent to see the NP at their usual source of care within 2 weeks of that most recent physician visit. Consented patients met with a research assistant in the waiting room at the time of their scheduled NP appointments and were escorted to the NP examination room located in the same clinic. Table 1 lists the NP duties performed during each visit. One NP conducted all patient visits and follow-up phone calls.

Providers practicing in clinics randomized to the NP had the option of refusing patients for NP co-management. Of the 1,452 patients receiving care in NP clinics during the study, 921 (63%) were consented and had at least 1 visit to the NP; of these, only 193 (21%) met inclusion criteria for our analyses (Fig. 1).

Medical Record Review

Through an electronic query of each participant’s EMR we obtained: patient race/ethnicity, sex, age at the time of the first visit, primary insurer, drug allergies, comorbid diseases (diabetes, congestive heart failure [CHF], coronary artery disease [CAD], or renal failure) as listed on the patient problem list, and classes of antihypertensive drugs on the medication list. In addition, we examined electronic prescribing records for each patient, collecting data on new antihypertensive medication prescribing within 7 days of each reminder date. We selected a period of 7 days to identify medication changes that were more likely the direct result of the reminder being seen by the provider.¹⁸

Trained abstracters then reviewed the EMR for each patient’s blood pressure for the first and last hypertension-related visits during the study period to obtain participants’ index and

Table 1. Samples of Computerized Medical Reminders and Case Management Duties

Samples
Sample Medical Reminders
A) Uncomplicated Black or elderly (>65 years old) patient with HTN: “This is a Black or elderly patient recorded as having hypertension without diabetes or heart disease, consider using a diuretic or calcium channel blocker for initial management of hypertension.”
B) Sample computerized reminder for uncomplicated White patient (≤65 years old) with HTN: “This is a White patient recorded as having hypertension without diabetes or heart disease, consider using a diuretic or beta-blocker for initial management of hypertension.”
C) Sample computerized reminder for patient with history of diabetes or heart failure with HTN: “This patient has a history of diabetes or heart failure, consider using an ACE inhibitor or diuretic for initial management of hypertension.”
Sample of Nurse Practitioner Duties
(A) Interview patients about the use, contraindications, and side effects of the medications used; remind the patient about the importance of medication compliance; ensure that medication refills are obtained as scheduled; and follow-up and reschedule patients who have missed follow-up visits with their primary care physicians after the initiation of therapy.
(B) Monitor blood pressure at scheduled appointments between primary care visits.
(C) E-mail or page providers when prescription doses were increased or other patient-related issues were discovered.
(D) Follow-up phone call to patients 1 week after visit to elicit and answer questions and to arrange a follow-up appointment if necessary

outcome visit blood pressures. We defined the last hypertension-related visit during the study period as the outcome visit to reflect the HEDIS measure of most recent blood pressure control and to allow the most time between physician exposure to CDS and clinical outcomes. Abstracters obtained blood pressure readings from 2 sources: (1) the vital signs field of the electronic medical record, which contains blood pressure measures typically entered by a nurse or medical assistant when the patient registers for an appointment, and (2) the text of the provider's encounter note for each visit. We examined the text of providers' notes for blood pressure readings because nurses/medical assistants did not uniformly transfer readings into the electronic vital signs field in all clinics until January of 2005 when all the affiliated clinics had electronic blood pressure devices that allowed them to directly download readings into the electronic record.

If more than 1 blood pressure was documented for a visit, we averaged them to obtain the mean systolic and diastolic blood pressure. We also classified each mean blood pressure as controlled (<130/80 for patients with diabetes or renal failure or <140/90 for other patients) or uncontrolled. Visits with undocumented blood pressures were also classified as uncontrolled. We found blood pressure was documented for 97% of index and 95% of outcome visits. For a random subset of 30 records, we tested for interrater reliability and found excellent agreement for our data abstraction instrument among reviewers ($\kappa=0.90$).

Sample Size

Our sample of 14 clinics was chosen on the basis of feasibility for CDS. After assuming a 20% increase in sample size to account for within-physician correlation, we estimated a minimum of 943 patients per CDS arm would provide 80% power to detect a 10% absolute increase in blood pressure control and guideline compliance rates in the intervention arm compared to the control arm. Before the intervention, we estimated that an 18-month trial would be sufficient to enroll 2,274 eligible patients in the CDS and usual care study arms.

Data Analyses

In our analyses, patients are the primary unit of analysis; however, randomization occurred at the level of the clinic and CDS was targeted to providers nested within the clinic. For this reason, all analyses were carried out using the SUDAAN software package to account for correlation between patients seen by the same physician and between physicians practicing within the same clinic.²⁷ We tested the effectiveness of the CDS using "intent-to-treat" analyses; all patients' whose initial visits occurred in an intervention clinic were assigned to that intervention throughout the analyses. Study endpoints included blood pressure control and mean systolic and diastolic blood pressures at the outcome visit. In addition, for each encounter where a reminder was generated or suppressed we examined whether the provider prescribed a medication in the recommended drug class within 1 week of the visit date. We compared patients' baseline demographic and clinical characteristics by study arm (Table 2) using the Pearson chi-square test for categorical variables and analysis of variance (ANOVA) for continuous variables. We report two-tailed *P* values with statistical significance set at $P \leq 0.05$ for these analyses.

We analyzed a series of multivariable logistic regression models to assess whether CDS was associated with the prescribing of a guideline recommended drug class or outcome visit blood pressure control compared to usual care. Using linear regression, we assessed whether the intervention was associated with improved outcome visit mean systolic and diastolic blood pressure. All models adjusted for patients' sociodemographic characteristics. To adjust for severity of illness, models included an adjustment for the number of patient care visits each patient received the year before the intervention. In addition, because the NP pilot was also aimed at improving blood pressure control, models predicting outcome blood pressure levels also contained an adjustment for NP and patients' baseline blood pressure. Data were available on every variable for all 2,027 participants for multivariable logistic regression and for 1,879 of the 2,027 participants

Table 2. Demographic and Clinical Characteristics of Study Participants by Intervention Arm

Variable	UC (N=1,048) N (%)	CDS* (N=786) N (%)	NP in UC* (N=120) N (%)	NP in CDS* (N=73) N (%)	P value†
Race and Ethnicity					
White	454 (43)	292 (37)	24 (20)	18 (24)	.06
Black	280 (27)	286 (36)	66 (55)	39 (53)	.02
Hispanic	284 (27)	192 (24)	23 (19)	12 (16)	.62
Other	30 (3)	16 (2)	7 (6)	4 (6)	.11
Male Sex	367 (35)	265 (34)	37 (31)	19 (26)	.64
Median Age	61	64	61	62	.32
Insurance					
Private	419 (40)	306 (39)	28 (23)	27 (37)	.19
Medicare	207 (20)	168 (21)	29 (24)	13 (18)	.51
Medicaid	128 (12)	89 (11)	17 (14)	6 (8)	.54
Free Care/Self-pay	294 (28)	223 (28)	46 (38)	27 (37)	.14
Median visits in the previous year	2	2	3	2	.32
Blood pressure controlled during first visit‡	452 (43)	343 (44)	35 (31)	23 (37)	.005
Median systolic blood pressure during first visit	138	136	138	136	.59
Median diastolic blood pressure during first visit	80	78	80	76	.07
JNC adherent medication at first visit§	578 (89)	435 (91)	68 (89)	42 (89)	.75

*UC=usual care, CDS=computerized decision support for all physicians within the practice, and NP=co-management with nurse practitioner for patients.

†Using chi-square tests for categorical variables and ANOVA for continuous variables.

‡Defined as <130/80 for diabetes and renal failure and <140/90 for all others

§N=1,249 for patients receiving medications at time of initial visit

(93%) for the multivariable linear regressions; participants without complete data were excluded from linear regressions. We report adjusted odds ratios with 95% confidence intervals from logistic models and the adjusted least square means from linear regression for each predictor along with its *P* value.

We performed several secondary analyses. To determine whether CDS reduced any racial/ethnic differences in measured outcomes, we included interaction terms for patient race/ethnicity and intervention arm. All nonsignificant interaction terms were removed from the final model. To examine any potential misclassification of patients without documented blood pressure, we repeated our analyses excluding patients with no documented index or outcome blood pressure.

RESULTS

Study Clinic and Participant Characteristics

Overall, there were 2,027 eligible patients in our sample, with 1,048 (52%) receiving care in usual care clinics, 786 (39%) receiving care in CDS clinics, 120 (6%) receiving care in NP clinics, and 73 (4%) receiving care in NP and CDS clinics (Fig. 1). Usual care clinics had significantly fewer non-Hispanic Black patients compared to clinics in the other intervention arms (Table 2). Demographic and clinical differences of study participants by intervention arm are presented in Table 2.

Blood Pressure Levels

Rates of blood pressure control were 42% at baseline and 46% at the outcome visit. After adjustment for patients' demographic and clinical characteristics, the number of prior visits, and levels of baseline blood pressure control, there were no differences between intervention groups in the odds of outcome blood pressure control (Table 3). Racial and ethnic

Table 3. Rates and Adjusted Odds of Blood Pressure Control at Outcome Visit

Variable	Blood Pressure Controlled Overall N=937 (46%) N (%)	Odds Ratio* (95% C.I.)
Intervention Arm		
Usual Care	527 (45%)	Reference
Computerized Support	410 (48%)	0.96 (0.78–1.19)
Received Case Management		
Yes	67 (35%)	0.88 (0.61–1.27)
No	870 (47%)	Reference
Race and Ethnicity		
White	425 (54%)	Reference
Black	265 (39%)	0.57 (0.45–0.73)
Hispanic	218 (43%)	0.61 (0.47–0.80)
Other	29 (51%)	0.99 (0.55–1.74)
Sex		
Men	326 (47%)	0.99 (0.82–1.21)
Women	611 (46%)	Reference
Insurance		
Private	388 (50%)	Reference
Medicare	181 (43%)	0.98 (0.75–1.29)
Medicaid	101 (42%)	0.93 (0.67–1.28)
Free Care/Self-pay	267 (45%)	1.03 (0.83–1.27)

*Using multivariable logistic regression adjusting for all listed covariates and patients' age, level of baseline blood pressure control, and number of hypertension-related visits in the year before the intervention period.

Table 4. Least Square Means for Adjusted Predictors of Systolic and Diastolic Blood Pressure at Outcome Visit

Variable	Mean Systolic Blood Pressure	P value*	Mean Diastolic Blood Pressure	P value*
Intervention Arm				
Usual Care	137	Reference	78	Reference
Computerized Support	138	0.67	77	.05
Received Case Management				
Yes	139	0.26	77	.70
No	137	Reference	77	Reference
Race and Ethnicity				
White	136	Reference	77	Reference
Black	139	0.008	77	.27
Hispanic	139	0.02	78	.009
Other	134	0.22	76	.66
Sex				
Men	136	0.02	77	.71
Women	138	Reference	77	Reference
Insurance				
Private	137	Reference	78	Reference
Medicare	136	0.44	76	.02
Medicaid	138	0.78	77	.77
Free Care/Self pay	138	0.22	78	.90

*Using multivariable linear regression adjusting for all listed covariates and patients' age and number of hypertension-related visits in the year before the intervention period; models predicting systolic and diastolic blood pressure were also adjusted for systolic and diastolic blood pressure at baseline, respectively.

minority patients were significantly less likely to have their blood pressure controlled at the outcome visit than non-Hispanic Whites. In the secondary analysis, which excluded patients without a documented index or outcome visit blood pressure, findings were consistent with our primary analyses demonstrating no effect of CDS on blood pressure control.

At the initial visits, participants had an average systolic blood pressure of 137 mmHg and diastolic blood pressure of 79 mmHg at baseline without significant differences between study groups (Table 2). After multivariable adjustment, there were no differences between intervention groups in mean systolic or diastolic blood pressure readings at outcome visits (Table 4). Racial/ethnic minority patients had slightly higher mean systolic blood pressure levels at the outcome visits than non-Hispanic Whites.

There were no differences in the effects of the interventions by patients' race/ethnicity in secondary analyses, suggesting CDS has no differential effect on reducing disparities in BP control or mean blood pressure levels over time.

JNC Adherent Prescribing

Overall, 90% of participants were taking a JNC-recommended blood pressure medication at the first visit without any differences between intervention groups at baseline (Table 2). During the intervention period, of the 20,977 visits for which a reminder was triggered or suppressed, providers prescribed a medication in the guideline-recommended class within 1 week of 1,218 visits (6%). Providers randomized to CDS were more likely to prescribe the recommended drug class when com-

Table 5. Adjusted Odds of Prescribing JNC Adherent Drug Class within 1 Week of Visit*

Variable	JNC Adherent Prescribing Odds Ratio (95% C.I.)
Intervention Arm	
Usual Care	Reference
Computerized Support	1.32 (1.09–1.61)
Race and Ethnicity	
White	Reference
Black	1.42 (1.09–1.85)
Hispanic	1.33 (1.03–1.71)
Other	1.42 (0.92–2.21)
Sex	
Men	0.84 (0.71–0.99)
Women	Reference
Insurance	
Private	Reference
Medicare	0.80 (0.62–1.02)
Medicaid	0.75 (0.56–1.00)
Free Care/Self-pay	0.43 (0.23–0.81)

*Using multivariable logistic regression adjusting for all listed covariates and patients' age and number of visits in the year before the intervention period.

pared to controls (7% versus 5%, $P < .001$). After multivariable adjustment, providers practicing in intervention clinics remained significantly more likely to prescribe a recommended drug than controls ($P = .002$) (Table 5). Non-Hispanic Black patients were also significantly more likely to receive a recommended drug compared to non-Hispanic Whites, and there were no significant interactions between receiving care in an intervention clinic and race and ethnicity in the multivariable model. Patients who were privately insured had significantly higher odds of receiving a new JNC adherent medication than other insurance groups and men were slightly less likely to receive new JNC adherent medication than women.

DISCUSSION

This study is, to our knowledge, the first trial of interventions to reduce disparities and improve the quality and outcomes of hypertension care for patients in academic hospital and community-based practices. Interventions conducted in these practice locations are particularly relevant because they provide chronic disease care for a disproportionately larger number of minority patients.²⁸ We found that CDS to physicians about hypertension treatment guidelines increased recommended medication prescribing compared to usual care. No significant improvements, however, were observed in measures of blood pressure control. In addition, we found that the effectiveness of our intervention did not differ by patients' race/ethnicity and mild disparities in blood pressure control persisted.

There are many potential explanations as to why our CDS had no impact with respect to blood pressure control. Our intervention was designed to remind physicians of the appropriate JNC drug class to prescribe for special hypertensive patients (i.e., beta blockade for patients with coronary disease) and was not designed to remind providers about appropriate intensification of antihypertensive therapy. In a study published in 2004, we examined patients receiving care in these settings and found that blood pressure remained poorly controlled among only 36% of hypertension-related visits, although patients were receiving a JNC-recommended medi-

cation for 81% of visits.¹⁴ We also found that minorities were more likely to have poorly controlled hypertension despite being more likely to receive a guideline-recommended drug. Secondary analyses of these data determined that Hispanics, the racial/ethnic group with poorest control, were less likely to have had their therapy appropriately intensified at any time over a 1-year period and that intensification of therapy was highly correlated with obtaining subsequent blood pressure control.^{14,29} Future interventions aimed at increasing rates of appropriate antihypertensive intensification should be studied to determine whether such CDS can improve hypertension outcomes and future studies aimed at reducing disparities may require more intensive, nonclinic-based interventions to overcome factors that pose particular challenges for traditionally underserved patients, such as lack of access to medications, medical mistrust, and environmental stress.^{15,30}

Focusing solely on blood pressure control as an outcome may detract attention from other evidence-based quality measures that can be more readily improved. For example, increasing appropriate ACE-inhibitor prescribing for hypertension patients with diabetes or congestive heart failure may be especially important,⁶ yet the associated outcomes related to increasing ACE-inhibitor use are longer term and would require a longer study period and larger sample size to document a meaningful effect. Focusing solely on measures, like blood pressure control, that can be defined and measured in the short term might understate the true impact of the guideline adherence.³¹

Our study has additional limitations. First, we relied on medical charts to measure quality of care and blood pressure control, which may have led to an underestimation of actual level of care provided.³² Second, whereas we assessed important markers of quality, some clinics might have improved in areas of care that we did not measure (e.g., improving provider experiences). Last, we did not survey providers about their opinions and knowledge of the clinical guidelines used as a basis for our CDS. Prior research has demonstrated that provider disagreement with guideline recommendations might be a significant barrier to provider guideline adherence.¹⁸

We conducted a pragmatic randomized trial of a CDS system within academic and community-based practices providing hypertension care to a multiethnic sample of patients. Whereas we found that CDS significantly improved appropriate medication prescribing, we observed no reduction in racial and ethnic disparities in care or improvement in blood pressure control. The substantial room for improvement in blood pressure control in the postintervention period suggests the need for future work focusing on different targets for CDS and the study of other practical interventions to reduce disparities in blood pressure control.

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APPENDIX

Algorithm for Hypertension Reminders

Rule 1 Algorithm (CAD and HTN).

Rule 2 Algorithm (DM and HTN).

Rule 3 Algorithm (CHF and HTN).

Rule 4 Algorithm (Renal Failure/HTN).

Rule 5 (Black Race/ HTN).

Rule 6 (Elderly/ HTN).

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