Electronic Health Records, Clinical Decision Support, and Blood Pressure Control

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Objectives: Adding clinical decision support (CDS) to electronic health records (EHRs) is required under meaningful use legislation, but there has been little national data on effectiveness in improving clinical outcomes. We sought to determine whether EHRs with CDS improved blood pressure control in US primary care visits.

Study Design: We used a cross-sectional, nationally representative survey.

Methods: We examined adult visits to primary care physicians using the 2007 and 2008 National Ambulatory Medical Care Survey (NAMCS).

Results: We found that patients had a mean age of 52 years, 34% were male, 15% had diabetes, and 70% were white. Rates of blood pressure control were significantly higher in visits where both an EHR and CDS (79%) were used, compared with visits where physicians used neither tool (74%; $P = .004$). Blood pressure control rates remained higher after adjusting for potential confounders. In unadjusted analyses, mean systolic blood pressure was 2 mm Hg lower in visits with the use of both an EHR and CDS, compared with visits where physicians used neither tool ($P = .03$), and this difference remained significant after adjustment.

Conclusions: The NAMCS shows that physician use of an EHR with CDS is associated with improved blood pressure control. These findings are important because small improvements in blood pressure control are associated with reductions in cardiovascular morbidity and mortality.

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For author information and disclosures, see end of text.

Hypertension contributes to over 50,000 deaths each year in the United States, with combined direct and indirect costs of $73.4 billion.[1] Despite widespread adoption of behavioral and case management approaches for hypertension and other chronic diseases that benefit from blood pressure control, such as diabetes, ischemic heart disease, cerebrovascular disease, and chronic kidney disease, national studies currently estimate that less than half of Americans with hypertension are controlled to less than 140/90 mm Hg.[2-6] The clinical relevance of blood pressure control in preventing devastating cardiovascular and cerebrovascular events is indisputable, and lack of control has been linked with disproportionate morbidity and mortality in underserved populations.[7,8] Hence, effective strategies to control hypertension are needed.

One possible intervention to improve blood pressure control is the expanded use of health information technology. Electronic health records (EHRs) with clinical decision support (CDS) have been touted as a solution to many deficiencies in the US healthcare system.[9] Current policy stipulates CDS as a criterion for "meaningful use" of EHRs.[10] However, to date there has been little rigorous evaluation of the impact of CDS on hypertension and none evaluating this outcome for CDS as implemented across the country.[11,12] Clinical decision support could theoretically impact hypertension management, because many effective, medical therapies exist but are currently underutilized by physicians and patients.[13] One example of CDS for hypertension is an electronic guideline–based reminder triggered when a patient's blood pressure is entered, although actual CDS varies widely among EHRs.[14,15]

National studies of EHRs and CDS have shown poor correlation between use and healthcare quality.[16,17] However, prior national studies have assessed only process measures, such as the process of checking blood pressure.[17] To address this limitation, we assessed the relationship of EHRs and CDS with a clinical outcome, blood pressure control, in order to determine whether EHRs and CDS improve the quality of hypertensive management in a nationally representative sample of patients.

METHODS

Overview

We categorized physicians by use of: 1) EHRs; 2) CDS;

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3) both; or 4) neither. We determined whether EHR and CDS use was associated with blood pressure control and mean blood pressure after adjusting for potential confounders. Our main outcomes of interest were differences in mean blood pressure and rate of blood pressure control (defined as both systolic blood pressure [SBP] <140 mm Hg and diastolic blood pressure [DBP] <90 mm Hg).

Take-Away Points

We used nationally representative data from the National Center for Health Statistics to compare blood pressure control in practices where physicians reported using electronic health records (EHRs), EHRs with clinical decision support (CDS), both, or neither in 2007 and 2008.

- Rates of blood pressure control were significantly higher in visits where both an EHR and CDS were used compared with visits where physicians used neither tool.
- Mean systolic blood pressure was 2 mm Hg lower in visits where both an EHR and CDS were used compared with visits where physicians used neither tool.

Data Source

We analyzed the National Ambulatory Medical Care Survey (NAMCS), a nationally representative survey of US ambulatory visits administered by the Centers for Disease Control and Prevention, National Center for Health Statistics (NCHS).[18] The NAMCS is a nationally representative, multistage probability survey of all ambulatory visits in the United States that weights each sampled visit to account for selection probability and nonresponse.[18] The NAMCS protocol has been approved by the NCHS Research Ethics Review Board, including a waiver of the requirement for informed consent of participating patients.

In 2007, 32,778 patient record forms were collected, of which 10,573 were for visits made by adults to primary care specialty physicians. In 2008, there were 28,741 visits with 10,351 primary care visits made by adults. The physician response rate was 72.7% in 2007 and 64% in 2008. In 2007, 7.8% of induction forms were missing a response to the question about CDS. In 2008, the figure was 7.2%. A large amount of race/ethnicity data were missing and the NCHS uses validated imputation methods to provide race and ethnicity data for all sampled visits.[19]

During recruitment in both years, trained interviewers asked physicians about EHR use using the following question: "Does your practice use electronic medical records (not including billing records)?" We considered an answer of "Yes, all electronic" or "Yes, part paper and part electronic" as a positive response for EHR use. To represent this question, we use the term "electronic health record" because it is more widely used throughout the medical literature and by national incentive programs, and connotes the maintenance of health, not just the treatment of illness.[20] Regardless of the answer to the EHR question, interviewers also asked, "Does your practice have a computerized system for reminders for guideline-based interventions and/or screening tests?" A physician who does not have an EHR may still have a computerized system providing CDS.

Information about individual physician demographic characteristics (eg, age and sex) and professional characteristics (eg, years in practice) is not available; however, physician specialty and employment status information is available. "Primary care specialty," as defined by the NCHS, includes Family Practice, General Practice, Internal Medicine, Pediatrics, Obstetrics, Gynecology, Adolescent Medicine, Sports Medicine, Geriatric Medicine, and Maternal/Fetal Medicine.[19] Practice type, ownership, and designation as a solo practice are also available.

Patient visit data include patient vital signs with separate SBP and DBP, patient date of birth, sex, race, ethnicity, insurance type, diabetes, and hypertension indicated through a diagnosis code, reason for visit, or chronic condition.

Data Analysis

We performed a retrospective, cross-sectional analysis of primary care visits. We used data collected during 2007 and 2008. Patients less than 20 years of age were excluded. We limited our analysis to primary care visits because blood pressure was missing in 44% of medical specialty visits and 82% of surgical specialty visits, as opposed to 9% of primary care specialty visits. We excluded visits with missing blood pressure from the analysis.

There were a small number of visits (11%) with missing data for either the exposure or outcome. To determine how sensitive our complete case analysis was to the missing data, we estimated the regression parameters using weighted estimating equations. This is an approach that uses all subjects' data and has been shown to be less biased than the typical complete case analysis.[21] The weighted estimating equation reweights visits depending on the probability of missing exposure and outcome data. Our complete case results were not substantially different with the weighted estimating equations approach (<5%); therefore, for simplicity we present only the complete case analysis.

We treated age as a continuous variable. Due to missing race/ethnicity data, we used the imputed race/ethnicity data provided by NCHS.[19] We examined the association between EHR and/or CDS use with patient demographics that are known to be associated with the blood pressure outcome, as well as diabetes due to evidence that diabetes comorbidity is associated with poor blood pressure control.[22] We collapsed insurance type into 5 categories (private, Medicare, Medicaid, self pay/no charge, workers' comp/other). We examined the

association between physician EHR and/or CDS use with potentially confounding physician and practice characteristics (ie, physician is owner, employee, or contractor). We collapsed practice ownership into 5 categories (owned by physicians, health maintenance organization [HMO], community health center [CHC], hospital, other).

Our main outcomes of interest were difference in mean SBP, difference in mean DBP, and difference in rate of blood pressure control (defined as <140/90 mm Hg). In secondary analyses, we performed a subgroup analysis for visits with a diagnosis of hypertension (indicated by diagnosis code, reason for visit, or chronic condition).

Statistical Analysis

Blood pressure was evaluated as both a continuous variable (mm Hg) and a binary variable (<140/90 mm Hg or ≥140/90 mm Hg).

We followed recommendations by the NCHS regarding the complex, clustered sampling design, and reliability of estimates. For all analyses, we used SAS-callable SUDAAN software (SAS v9.2 SUDAAN 10.0 RTI, Research Triangle Park, North Carolina) procedures to account for weighting, stratification, and clustering. We considered $P < .05$ statistically significant.

Bivariate analyses to explore differences in patient and practice characteristics between exposure groups were performed using χ^2 tests (for categorical variables) and Wald F tests (for continuous variables). From these bivariate analyses, we report a weighted, unadjusted proportion of visits and mean age in each exposure group.

We performed unadjusted analyses (unadjusted for covariates, but accounting for the complex survey design) between blood pressure control and patient and practice characteristics, as well as significant associations and P values for the t test for each category of patient characteristics compared with the reference group.

We report mean SBP and DBP in each exposure group and the P value from the Wald F test. Similar unadjusted analyses were performed between the exposure of interest and blood pressure as a dichotomous outcome. We report P values for the t test for each exposure category compared with the reference group.

For multivariable linear regression analyses for the continuous blood pressure outcome, we included covariates that we found to be significantly associated with the exposure (patient age, sex, race, and insurance type, as well as practice ownership) and we included diabetes due to a priori knowledge. We examined the relationship with blood pressure control utilizing multivariable logistic regression and adjusting for the same factors.

Last, we repeated all analyses in the subgroup of visits where hypertension was indicated as a diagnosis.

RESULTS

Visit Characteristics

In 2007 and 2008, we sampled 20,924 visits by adults to primary care physicians, representing 826 million visits nationally. The mean age of patients was 52 years, 34% of visits were made by men, 15% had diabetes, 70% were white, 11% were black, and 12% were Hispanic (Table 1). Private insurance paid for 59% of visits, 24% were paid by Medicare, and 9% by Medicaid. Physician-owned practices represented 79% of visits, while 6% of visits were to practices owned by hospitals, 4% were to practices owned by CHCs, and 3% were to practices owned by HMOs. Physicians using only an EHR constituted 15% of visits, while 10% of visits were to physicians using only CDS, 27% were to physicians using both an EHR and CDS, and 48% were to physicians using neither.

Blood Pressure Control

Regardless of EHR and/or CDS use, blood pressure control rates were higher for visits by white patients compared with visits by black patients (75% vs 72%; $P = .02$) at visits by women compared with men (79% vs 70%; $P < .001$), at visits by patients without diabetes compared with those with diabetes (77% vs 68%; $P < .001$), at visits paid for by private insurance compared with visits paid for by Medicare (78% vs 67%; $P < .001$), and at visits to practices owned by an HMO compared with visits to physician-owned practices (82% vs 76%; $P = .02$). Age was significantly inversely associated with blood pressure control ($P < .001$). Of the patients with a diagnosis of hypertension, 59% were controlled as opposed to 84% of people who did not have a diagnosis of hypertension.

Association Between EHR and CDS Use and Blood Pressure

We found significant relationships between combined EHR/CDS use and blood pressure. In unadjusted analyses, mean SBP was 2 mm Hg lower in visits with use of both an EHR and CDS, compared with visits where physicians used neither tool ($P = .03$; Table 2). When examining rates of blood pressure control, we found that the rate was 5% higher in visits where physicians used both an EHR and CDS, compared with visits where physicians used neither tool ($P = .004$; Table 3).

In multivariable analyses, the significant difference in mean SBP also remained significant in fully adjusted models (125 mm Hg in the visits with use of both an EHR and CDS vs 126 mm

Table 1. Patient and Clinic Characteristics of 2007-2008 National Ambulatory Medical Care Survey Participants Categorized by Physician Use of Electronic Health Records and Clinical Decision Support

	Total	Without EHR or CDS	With EHR and Without CDS	Without EHR and With CDS	With EHR and CDS	P[a]
Patient characteristics		**n = 9704[b]**	**n = 2783[c]**	**n = 1827[d]**	**n = 5433[e]**	
Age, mean (SE)[f]	51.9 (0.54)	51.7 (0.79)	55.0 (1.43)	49.5 (1.49)	51.3 (0.92)	.06
Weighted visit						
Overall	—	48%	15%	10%	27%	
Male sex	34%	32%	39%	35%	32%	.05
Race/ethnicity						.03
White	70%	68%	74%	72%	70%	
Black	11%	15%	6%	9%	10%	
Hispanic	12%	12%	11%	13%	13%	
Other	6%	6%	9%	5%	7%	
Diabetes	15%	14%	14%	15%	16%	.70
Hypertension	33%	33%	36%	36%	32%	.58
Insurance type						.04
Private insurance	59%	57%	56%	63%	62%	
Medicare	24%	24%	30%	20%	23%	
Medicaid	9%	10%	6%	7%	9%	
Self pay/no charge	6%	7%	4%	8%	5%	
Workers' comp/other	3%	3%	4%	2%	3%	
Practice ownership						.01
Physician	79%	85%	78%	84%	69%	
Hospital	6%	6%	6%	8%	5%	
CHC	4%	3%	4%	2%	6%	
HMO	3%	1%	4%	0%	7%	
Other	8%	5%	9%	6%	13%	

CDS indicates clinical decision support; CHC, community health center; EHR, electronic health record; HMO, health maintenance organization.
[a] *P* value for significant difference across EHR/CDS groups in either mean age or weighted proportion obtained by χ^2 test for categorical and Wald *F* test for continuous predictors.
[b,c,d,e] Unweighted N. Weighted N = [b]372,292,620, [c]115,838,764, [d]79,526,349, and [e]214,452,975.
[f] Standard errors estimated using SUDAAN (SAS v9.2 SUDAAN 10.0 RTI, Research Triangle Park, North Carolina) procedure to account for weighting and clustering.

Hg in the visit with use of neither, *P* = .006). Visits to physicians who used both an EHR and CDS compared with those who used neither still had a significantly higher rate of blood pressure control after adjusting for patient age, sex, race/ethnicity, diabetes, insurance type, and practice ownership (Table 3).

We did not find significant association between EHR use alone and blood pressure control (Table 3). There were no significant differences in DBP in unadjusted or adjusted analyses.

Hypertension Subgroup Analysis

In subgroup analyses including only visits with a diagnosis of hypertension, mean SBP was 2 mm Hg lower in visits with the use of both an EHR and CDS as compared with visits where physicians used neither tool (*P* = .02; Table 2). This difference was borderline significant in adjusted analyses (133 mm Hg in visits with use of both an EHR and CDS vs 135 mm Hg in visits with use of neither, *P* = .05). There were no significant pairwise differences in mean DBP in unadjusted or adjusted analyses in the hypertension subgroup.

Among patients with a history of hypertension, the rate of blood pressure control was higher in visits with both an EHR and CDS compared with those with neither (63% vs 56%, *P* = .01) and this difference remained significant after multivariable adjustment (62% vs 56%, *P* = .04). We compared visits without EHR or CDS with both visits where physicians

Table 2. Mean Blood Pressure Stratified by Physician Use of Electronic Health Records and Clinical Decision Support

	Overall	Without EHR or CDS	With EHR and Without CDS	Without EHR and With CDS	With EHR and CDS	*P*[a]
Adult primary care visits		**n = 9704[b]**	**n = 2783[c]**	**n = 1827[d]**	**n = 5433[e]**	
SBP, mean (SE)[f]	126 (0.38)	126 (0.59)	127 (0.86)	126 (1.2)	124 (0.57)	.07
DBP, mean (SE)	76 (0.22)	76 (0.22)	76 (0.55)	76 (0.63)	75 (0.42)	.29
Adult hypertension visits[k]		**n = 3207[g]**	**n = 951[h]**	**n = 621[i]**	**n = 1709[j]**	
SBP, mean (SE)[f]	134 (0.42)	135 (0.58)	134 (1.02)	135 (1.26)	133 (0.84)	.14
DBP, mean (SE)	78 (0.31)	79 (0.48)	77 (0.61)	80 (0.75)	78 (0.63)	.04

CDS indicates clinical decision support; EHR, electronic health record; DBP, diastolic blood pressure; SBP, systolic blood pressure.
[a]*P* value for significant difference across exposure groups obtained by Wald F test.
[b,c,d,e,g,h,i,j]Unweighted N. Weighted N = [b]372,292,620, [c]115,838,764, [d]79,526,349, [e]214,452,975, [g]122,080,136, [h]41,460,904, [i]28,659,817, and [j]69,220,640.
[f]Standard errors estimated using SUDAAN (SAS v9.2 SUDAAN 10.0 RT1, Research Triangle Park, North Carolina) procedure to account for weighting and clustering.
[k]Subgroup analysis among hypertension visits.

reported using EHR alone or using CDS alone and found no associations with better blood pressure control (*P* >.1 for all comparisons).

DISCUSSION

In this examination of a large, nationally representative survey of primary care visits, we found that blood pressure control was significantly associated with combined EHR and CDS use. To our knowledge, this is the first nationally representative study to demonstrate potential benefit of combined EHR and CDS use for an intermediate clinical outcome.

Theoretically, there are numerous reasons why combined EHR and CDS use may improve hypertension control. Clinical decision support brings new guidelines to the point of care. In a study of self-reported hypertension treatment practices, 43% of physicians would not initiate therapy for an SBP of 160 mm Hg, and 41% of physicians had not heard of or were not familiar with the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of Blood Pressure (JNC) guidelines.[23] The immediacy of a point-of-care reminder may impact clinical inertia, which has been cited as a major cause of undertreated hypertension.[24] Other studies have shown that CDS can improve compliance with drug class recommendations.[14] In addition, an EHR is able to flag persistent uncontrolled blood pressure, which often goes unrecognized over time.[25] For all of these reasons, it is plausible that an EHR with CDS functionality may improve hypertension control if the CDS addresses blood pressure control.

This finding about CDS is novel because most positive studies of CDS have been conducted in academic medical centers with internally designed EHRs, many of which are highly advanced compared with commercially available products.[12] In addition, the organizational structure of academic hospitals assists academic primary care clinics and may allow for rapid implementation and ongoing training and support. Therefore, our examination of the impact of EHRs in real-world primary care settings, many of which are solo practices, is important.

Our consistently positive findings differ from other prior national studies that have examined the impact of EHRs on clinical processes and quality of care because others have reported mixed results.[11,16,17] For example, in their NAMCS analyses, Linder et al[16] found an association of EHR use with better quality for only 2 of 17 measures, and association with worse quality for 1 measure. Similar methods were used in

Table 3. Proportion of Visits With Blood Pressure <140/90 mm Hg Stratified by Physician Use of Electronic Health Records and Clinical Decision Support

	Unadjusted Proportion[a]	*P*[a]	Adjusted Proportion[b]	*P*[b]
Without EHR and without CDS	74%	reference	74%	reference
With EHR and without CDS	73%	.76	75%	.45
Without EHR and with CDS	77%	.40	76%	.52
With EHR and CDS	79%	.004	79%	.003

CDS indicates clinical decision support; EHR, electronic health record.
[a]Unadjusted analysis accounts for complex survey design, but does not adjust for possible confounders.
[b]Utilizing multivariable logistic regression to adjust for patient age, sex, race, diabetes, insurance type, and practice ownership.

a 2011 study where Romano and Stafford et al[17] found an association of EHR use with better quality for only 1 of 20 measures when compared with no EHR use and an association of combined EHR and CDS use with better quality for only 1 of 20 measures. One difference in our study is that we focused on primary care visits, as opposed to the previously mentioned studies, which included all ambulatory visits. Also, both studies found improvement for measures that would not logically be expected to improve with EHR use (eg, diet counseling and avoidance of routine testing). In contrast, our positive findings apply to blood pressure control and it is conceivable that CDS, as implemented, addresses blood pressure control. First, vital sign entry is a standard feature of EHRs.[10] Second, blood pressure control is a quality improvement target for multiple common conditions such as diabetes, ischemic heart disease, cerebrovascular disease, and chronic kidney disease; therefore, it may be incorporated into any number of CDS modules.

Similar to previous national studies, we found that EHR use alone is not associated with improved healthcare quality.[16,17] Our work is particularly important because current health policy stipulates "meaningful use" of EHR, which affects providers who are implementing an EHR to take advantage of federal financial incentives or to avoid future penalties; they must prove that their system has CDS. Our findings are pertinent to the current debate on "meaningful use" because they are the first nationally representative results espousing a benefit of CDS for a clinical outcome.

The JNC guidelines recommend that blood pressure be controlled to less than 140/90 mm Hg, yet national studies show that many Americans exceed this level.[2,13] Meta-analyses have shown that bringing SBP under control yields an average life expectancy gain of about 1.5 years, and has greater impact among groups with life expectancy lower than the national average (eg, 2.8 years for a Southern, low income, black woman living in a rural area).[7] To further place the magnitude of our findings into perspective, the mean absolute SBP difference of 2 mm Hg between clinics with EHRs and CDS versus clinics with neither is greater than that typically seen with behavioral interventions. A recent meta-analysis of on-screen, point-of-care reminders showed a median reduction in SBP of 1 mm Hg.[4,11] Thus, the 5% absolute difference in blood pressure control rates and 2–mm Hg difference between visits with an EHR and CDS versus visits with neither tool has considerable public health implications.

For these analyses, we utilized a data source and methods that are well established.[2,26-29] Despite these strengths, there are several limitations to this study. First, it is a cross-sectional study, making it impossible to determine whether improved blood pressure control was caused by the use of EHRs with CDS or if better controlled patients are more likely to visit practices that use EHRs with CDS. However, in our multivariable models we adjusted for patient sociodemographics and clinical characteristics previously associated with poorly controlled blood pressure and our findings persisted. Second, the measures for the exposure present limitations. Logically, CDS will only impact blood pressure control if the CDS addresses hypertension, and among CDS for hypertension, reminders may range from general screening alerts to alerts tailored to individual patients. The survey question about guideline-based reminders did not state whether the reminders are specific to hypertension. Third, the NAMCS instrument does not measure quality initiatives or practice structure. For example, a practice with any computerized system is better able to provide performance audit as feedback to physicians, which can impact quality.[30,31] Or a patient-centered medical home model would likely have point-of-care CDS alongside population hypertension surveillance.

In conclusion, we have found that meaningful use of health information technology is associated with improved blood pressure in primary care visits. Specifically, patient blood pressure is more likely to be adequately controlled at visits where providers use both an EHR and CDS. These findings suggest that when practices purchase EHRs they should consider CDS features, not only to comply with federal policy, but also due to scientific evidence of benefit. Current interest in the patient-centered medical home and accountable care organizations ensures that we will continue to assess the interplay among health information technology, practice structure, and payment incentives.

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