ORIGINAL RESEARCH

Risk-Adjusted Comparison of Blood Pressure and Low-Density Lipoprotein (LDL) Noncontrol in Primary Care Offices

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Objectives: **Population-level control of modifiable cardiovascular disease (CVD) risk factors is suboptimal. The objectives of this study were (1) to demonstrate the use of electronically downloaded electronic health record (EHR) data to assess guideline concordance in a large cohort of primary care patients, (2) to provide a contemporary assessment of blood pressure (BP) and low-density lipoprotein (LDL) noncontrol in primary care, and (3) to demonstrate the effect of risk adjustment of rates of noncontrol of BP and LDL for differences in patient mix on these clinic-level performance measures.**

Methods: **This was an observational comparative effectiveness study that included 232,172 adult patients ≥18 years old with ≥1 visit within 2 years in 33 primary care clinics with EHRs. The main measures were rates of BP and LDL noncontrol based on current guidelines and were calculated from electronically downloaded EHR data. Rates of noncontrol were risk-adjusted using multivariable models of patient-level variables.**

Results: **Overall, 16.0% of the 227,122 patients with known BP and 14.9% of the 136,771 patients with known LDL were uncontrolled. Clinic-level, risk-adjusted BP noncontrol ranged from 7.7% to 26.5%, whereas that for LDL ranged from 5.8% to 23.6%. Rates of noncontrol exceeded an achievable benchmark for 85% (n = 28) and 79% (n = 26) of the 33 clinics for BP and LDL, respectively. Risk adjustment significantly influences clinic rank order for rate of noncontrol.**

Conclusions: **We demonstrated that the use of electronic collection of data from a large cohort of patients from fee-for-service primary care clinics is feasible for the audit of and feedback on BP and LDL noncontrol. Rates of noncontrol for most clinics are substantially higher than those achievable. Risk adjustment of noncontrol rates results in a rank-order of clinics very different from that achieved with nonadjusted data. (J Am Board Fam Med 2013;26:658–668.)**

Keywords: **Blood Pressure, Cholesterol, Clinical Practice Guideline, Electronic Health Records, Feedback, Health Information Management**

More than one-third of American adults have one or more of the following cardiovascular diseases (CVDs): hypertension, coronary heart disease (CHD), stroke, or heart failure. In 2008 CVD was the primary cause of 32.8% of all US deaths. Similarly, CVD is the most common reason for hospi-

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talization, accounting for 18% of the total of 34,369,000 hospitalizations and one-fourth of the total cost of inpatient hospital care in the United States.[1] Between 2010 and 2030, total direct medical costs of CVD (in real 2008 dollars) are projected to triple, from $273 billion to $818 billion.[2]

Modifiable risk factors account for most CVD. The Atherosclerosis Risk in Communities Study followed 14,162 middle-aged adults who were free of recognized CVD at entry for a mean of 13.1 years.[3] The vast majority (86.2%) of the 1492 CVD events occurred in the 66.5% of the population with ≥1 risk factor. The population-attributable fraction suggested that having at least 1 elevated risk factor accounted for 70.2% of CVD events.

Despite effective antihypertensive and antihyperlipidemic medications that have been shown to reduce major adverse cardiovascular events (MACEs) in large-scale, randomized trials,[4,5] the control of blood pressure (BP) and cholesterol in the United States remains suboptimal. National Health and Nutrition Examination Survey (NHANES) data from 2005 to 2006 showed that 20.3% of US adults had uncontrolled BP (defined as ≥140/90 mmHg).[6] For each 10-mmHg decrease in systolic BP, the average risk of heart disease and stroke mortality decreases by 30% and 40%, respectively.[7] An estimated 33,500,000 adults ≥20 years old have total cholesterol levels ≥240 mg/dL, a prevalence of 16.2%.[1,8] Cohort studies based on half a million men and 18,000 ischemic heart disease events estimate that a 10% long-term reduction in serum cholesterol would lower the risk of ischemic heart disease at age 40 by 50%.[9]

The objectives of this article are to (1) demonstrate the use of electronically downloaded electronic health record (EHR) data to assess guideline concordance in a large cohort of primary care patients, (2) provide a contemporary assessment of noncontrol of BP and low-density lipoprotein (LDL) levels in primary care, and (3) demonstrate the effect of risk adjustment of rates of noncontrol of BP and LDL for differences in patient mix on these clinic-level performance measures.

Methods

Study Design

This is an observational study comparing evidence-based, risk-adjusted rates of noncontrol of BP and LDL across 33 clinics.

Participants

Table 1 shows the population characteristics. The mean (S.D.) age was 45.6 (15.7) years; body mass index (BMI) 27.7 (6.2) kg/M^2, and number of visits within two years 3.4 (5.0).

Setting

This study is being conducted in the Distributed Ambulatory Care Research in Therapeutics Network (DARTNet) Collaborative, a group of practice-based research networks that are working to build a national collection of EHR data.[10–12] DARTNet, in collaboration with QED Clinical, Inc. (doing business as CINA; http://www.cina-us.com/), has developed data extraction, transformation, and loading (ETL) processes that allow aggregation of data from disparate EHRs into a harmonized database. The Cardiovascular Risk Reduction Learning Community (CRRLC) includes 33 primary care clinics from 10 private, fee-for-service health care delivery organizations participating in DARTNet. Two organizations were affiliated with a academic medical center, 1 provided sites for a community residency program affiliated with an academic medical center, and the remainder were not academically affiliated.

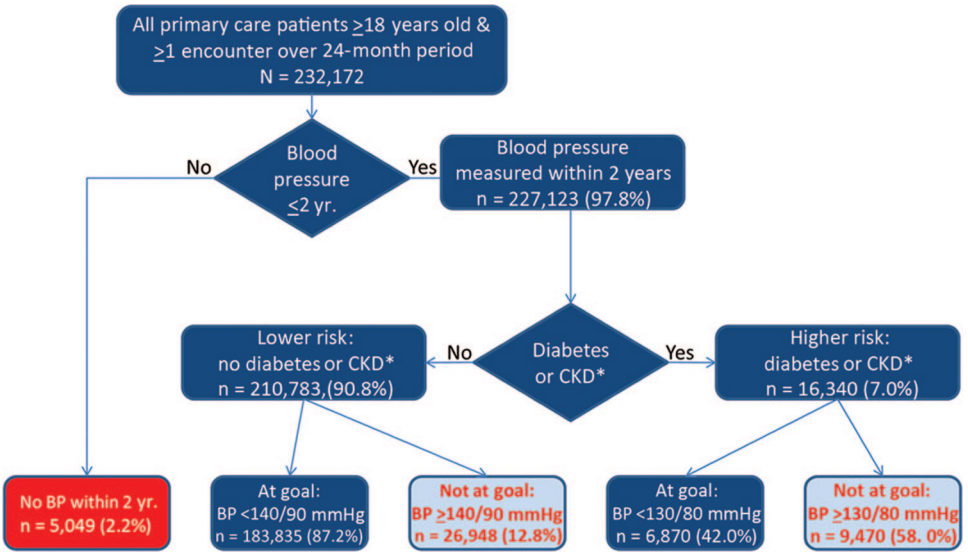
Participants

The study population consists of all 232,172 patients who met the overall criteria of age ≥18 years and ≥1 clinic appointment within the preceding 2 years.

Guideline Translation to Calculate Rates of BP and LDL Noncontrol

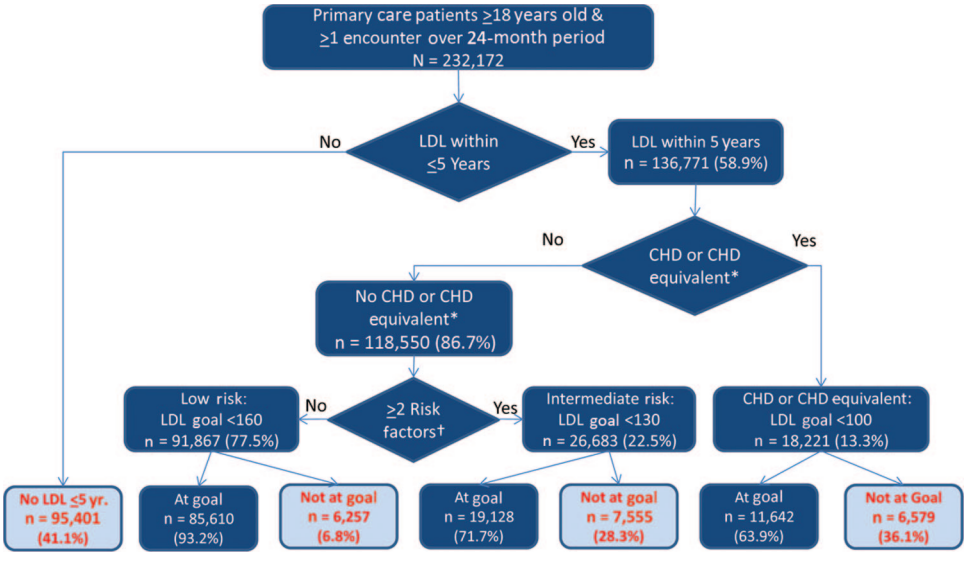
We relied extensively on the guidelines developed under of the auspices of the National Heart, Lung, and Blood Institute for control of BP (the Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure [JNC7])[13] and LDL cholesterol (National Cholesterol Education Program [NCEP]).[14] As have others,[15] we found translating guidelines from their published, largely text format into algorithms suitable for electronic data analysis to be a challenging task requiring multiple revisions. Our CRRLC Steering Committee, comprising 4 primary care physicians recruited from participating clinics and 2 university-based subject matter experts, was central in resolving questions in this process.

Figure 1. Flow diagram illustrating both criteria for blood pressure (BP) control from the Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure and the numbers (percentages) of patients at each step. CKD, chronic kidney disease.



Calculation of noncontrol rates using both the JNC7 and NCEP guidelines required categorizing patients according to their risk for MACEs using CVD risk factors and presence or absence of CHD. The results of the translation of JNC7 and NCEP guidelines into hierarchical flow diagrams, on the basis of which electronic algorithms to calculate noncontrol rates were con-

Figure 2. Flow diagram illustrating National Cholesterol Education Program (NCEP) criteria for low-density lipoprotein (LDL) control and numbers (percentages) of patients at each step. *Coronary heard disease (CHD) equivalent includes diabetes, cerebral vascular disease, peripheral vascular disease, and abdominal aortic aneurysm. †NCEP nonlipid risk factors include age (male >45 years, female >55 years); family history of premature coronary artery disease; current cigarette smoking; hypertension (blood pressure >140/90 or taking antihypertensive medication); low high-density lipoprotein (HDL) (>40 mg/dL; if HDL >60 mg/dL, subtract one risk factor).



structed, are shown in Figures 1 and 2, respectively; additional details are provided in Appendix Tables 1 and 2, available online.

Data Sources/Management

The data reported here are drawn from EHR data about clinic visits, including problem lists, patient demographics, BP measurements, and laboratory data between January 1, 2006, and December 31, 2010. For both the JNC7 and NCEP guidelines, the data required to assess and adjust for risk the guideline noncontrol rates include BP and LDL measurements, concomitant comorbidity, and other risk factors for MACE (eg, age, cigarette smoking, and HDL-cholesterol). In addition, we collected data on clinic appointments and encounters, antihypertensive and antihyperlipidemic medications prescribed, height, weight, year of birth, and tobacco use/abuse. When ≥2 BP measurements were available, we used the average of the 2 most recent values. Age, BP, LDL levels, and HDL levels are relatively easy to retrieve from the EHRs of CRRLC organizations, but the definition of comorbidities using *International Classification of Diseases, Ninth Revision* (ICD-9), codes requires grouping into clusters, which are not provided in either the complete JNC7[13] or NCEP[14] documents. We used the clustering of ICD-9 codes into comorbidities developed for ambulatory care by Schneeweiss et al[16] and subsequently modified by Pace et al.[17] This grouping did not contain ICD-9 code clusters for chronic kidney disease and abdominal aortic aneurysm, which we created using our clinical judgment (Appendix Table 3, available online).

All data were imported nightly from the practice EHRs to a relational clinical data repository (CDR) located behind the firewall of each organization using proprietary software mapping tools developed by CINA. The CINA software used for ETL were tools that were already in place and being used by each organization to produce point-of-care clinical decision support reports and population management reports. The CDR provided a near real-time source of standardized and codified data used in point-of-care clinical decision making and the audit and feedback reports, as well as the periodic data extractions used for this article. CINA, which had a Business Associate Agreement already in place with each organization, served as our data transfer agent, providing us with the limited data sets required for the analyses reported here.

Data Validation by CINA

Because this research was conducted using data extracted and translated from the EHRs to a secondary CDR by our data transfer agent, CINA, it was imperative to understand and validate the data received through a multistep process. Data validation was largely the responsibility of CINA as the ETL vendor in place at each organization before the initiation of this project. Because CINA provides software tools that use data from the CDR in the course of clinical care and decision making, CINA has several processes in place to ensure the reliability and validity of the data that is contained within the CDR. Data reliability testing by CINA includes the following: (1) patient-level sampling comparing the data imported into the CDR with the source data as it is represented in the EHR; (2) daily use in clinical practice of the data in the CDR through the point-of-care clinical decision support tool and population management tools provided by CINA; and (3) data reliability testing with each data extraction for research analysis.

Data Validation Exercises by the Investigators

Data validation studies performed by the investigators included (1) an assessment of data distribution for continuous variables to identify implausible or nonphysiologic values; (2) comparisons of distributions of continuous variables by organization to look for problems with units (ie, English/metric), differing analytic methods, and mapping anomalies; and (3) an examination of the distribution of categorical responses to look for clinically conflicting findings. These data validation studies were done independent of CINA, but the results were shared with CINA for wider improvement in data quality.

We constructed tables of the distributions of each continuous variable that included the value, number, and percentage of each observation and cumulative percentage of all observations. In addition, we found that viewing graphs of these distributions as a group was useful. Using our clinical judgment and the proportions of values in the tails of the distributions, we excluded the following values from further analysis: systolic BP >260 or <50 mmHg, diastolic BP >200 or <0 mmHg, height >90″ or <45″, weight >500 or <50 lb, creatinine >20 or <0.2 mg/dL, total cholesterol >450 or <50 mg/dL, LDL >300 or <10 mg/dL, and HDL-cholesterol >150 or <5 mg/dL. The pro-

portion of values deleted varied from 0.005% for systolic BP to 0.5% for creatinine.

When comparing distributions of data by clinic, we discovered a few anomalies, one of which was due to one organization using a different cholesterol fractionation technique; others probably were due to mapping variances. These anomalies were corrected in most cases by examining the organization-specific field names. Short of manual chart review—a nearly impossible task for 232,172 patients—there is no way to check the accuracy of ICD-9 coding of comorbidities in the EHR, which enter into the calculation of guideline concordance and its risk adjustment; therefore we accepted the ICD-9 coding without editing or verification.

A value for BP in the preceding 2 years was missing in only 2.2% (5,049 of 232,272 patients) of patients; a value for LDL in the preceding 5 years was missing for in 41.1% (95,401 of 232,172 patients); and height and weight were missing in 9.0% and 2.7%, respectively. These missing values were not imputed, meaning that the sample sizes in the multivariable models were reduced (Appendix Tables 4 and 5, available online).

Data Security and Privacy Protection

Each of the 10 participating organizations signed a data use agreement allowing the use of their data; this agreement specifies the data elements used and that Health Insurance Portability and Accountability Act identifiers, with the exception of dates of service, were deleted before transfer to a secure server within the Department of Family Medicine at the University of Colorado School of Medicine.

Institutional Review Board

The protocol for the CRRLC, a waiver of informed consent, and a waiver of Health Insurance Portability and Accountability Act authorization have been approved by the Colorado Multiple Institutional Review Board and an institutional review board sponsored by the American Academy of Family Physicians that represents all participating clinics.

Statistical Analyses

We used previous research and our clinical judgment to select the 31 variables (listed in Table 1) to describe the cohort and to develop risk-adjustment models using stepwise logistic regression with BP or LDL noncontrol as the dependent variables.

Table 1. Population Characteristics (n = 232,172)

Selected Patient Characteristics and Risk-Adjustment Variables	Prevalence
Adverse drug effects	1,134 (0.49)
Age (years)	
18–40	95,639 (41.2)
41–60	94,978 (40.9)
61–80	35,971 (15.5)
>80	5,584 (2.4)
Alcohol or drug abuse	11,326 (4.9)
Anemia	10,442 (4.5)
Body mass index (kg/m^2)	
<18.5 (underweight)	3,557 (1.5)
18.5–24.9 (normal)	67,834 (29.2)
25.0–29.9 (overweight)	73,852 (31.8)
30.0–34.9 (class I obese)	39,744 (17.1)
35.0–39.9 (class II obese)	16,041 (6.9)
≥40.0 (class III obese)	9,967 (4.3)
Missing	21,177 (9.1)
Cataract/aphakia	4,081 (1.8)
Cerebral vascular disease or CVA	3,612 (1.6)
Congestive heart failure	1,518 (0.7)
Depression or anxiety	50,822 (21.9)
Diabetes mellitus	14,804 (6.4)
Ischemic heart disease	6,007 (2.6)
Hepatitis or mononucleosis	2,356 (1.0)
Hyperlipidemia	65,343 (28.1)
Hypertension	58,849 (25.3)
Chronic kidney disease	2,667 (1.1)
Male sex	101,184 (43.6)
Medical or surgical aftercare	12,871 (5.5)
Neoplasm, benign	26,926 (11.6)
Neoplasm, malignant	3,308 (1.4)
Obesity	16,089 (6.9)
Peripheral vascular disease	1,835 (0.8)
Personality disorders	192 (0.1)
Pulmonary disease, chronic obstructive	3,709 (1.6)
Prostatitis/BPH	7,821 (3.4)
Psychosocial problem	1,463 (0.6)
Respiratory tract infection, acute lower	22,820 (9.8)
Respiratory tract infection, acute upper	47,984 (20.7)
Rhinitis, chronic	49,977 (21.5)
Routine health maintenance	126,419 (54.5)
Schizophrenia or affective psychosis	5,660 (2.4)
Visits per year (n)	
1 or 2	141,393 (60.9)
3 or 4	47,948 (20.7)
5 or 6	17,764 (7.7)
>6	25,067 (10.8)

Data are n (%).
BPH, benign prostatic hyperplasia; CVA, cerebrovascular accident.

The cumulative c-index was computed after each step.

We calculated the risk of each patient having BP or LDL noncontrol using the parameter estimates from each model and summed this expected risk by clinic (E), which was compared with the observed number of patients with noncontrol (O) in each clinic as the O-to-E ratio. For ease of clinical interpretation we converted the O-to-E ratio into a risk-adjusted percentage of noncontrol by multiplying each clinic's O-to-E ratio by the observed mean rate of noncontrol for all patients across all clinics. We calculated an achievable benchmark of care patterned after the work of Kiefe and colleagues,[18–21] except clinics were rank-ordered by their risk-adjusted rates of noncontrol. Our achievable benchmark is the weighted average noncontrol rate for the top-ranked clinics, providing care for approximately 10% of all patients.

Results

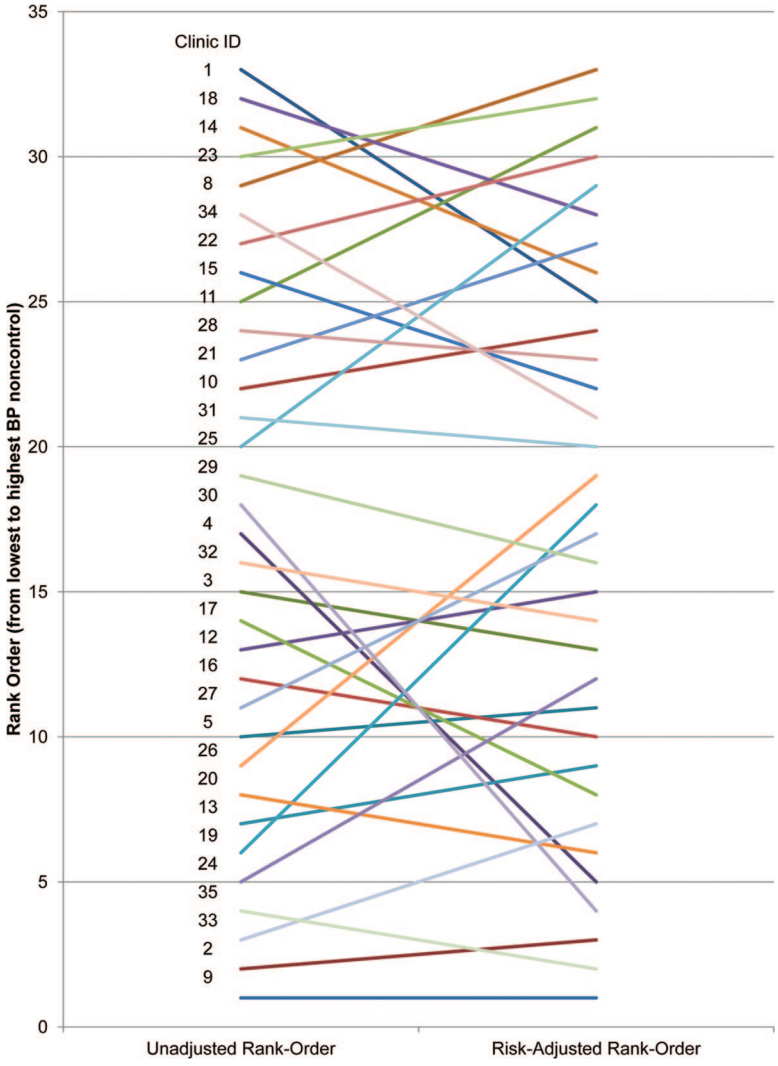
Unadjusted BP Noncontrol

There was no BP measurement within the preceding 2 years for 2.2% of patients (5,049 of 232,172). Overall, 16.0% of patients (36,418 of 227,123) with measured BPs had uncontrolled BP (Figure 1). For patients without diabetes or CKD, 12.8% (26,948 of 210,783) had uncontrolled BP (≥140/90 mmHg). For patients with diabetes or CKD, 58.0% (9,470 of 16,340) had uncontrolled BP (≥130/80 mmHg).

Risk-Adjusted BP Noncontrol

The multivariable model of patient-level variables associated with BP noncontrol is shown in Appen-

Figure 3. Comparison of rank-order of clinics by unadjusted and risk-adjusted blood pressure (BP) control.



dix Table 4, available online. The c-index for the full model was 0.822, whereas the c-index for the first 10 variables entering the model, which were used in the risk adjustment of BP noncontrol, was 0.821. Online Appendix Figure 1 shows the risk-adjusted percentage of noncontrol by clinic, which varied from a high of 26.5% to a low of 7.7%, with a weighted average across all clinics of 15.9%. The achievable benchmark was 10.7% noncontrol. Of the 33 clinics, 28 (85%) had noncontrol rates with 95% confidence intervals higher than this benchmark.

Figure 3 shows the considerable differences the rank-order of clinics by the unadjusted rate of BP noncontrol versus the rank-order of the risk-adjusted noncontrol rate, with 4 clinics changing rank-order by ≥10 places, 8 clinics changing rank-order between 5 and 9 places, and 21 clinics changing rank-order ≤4 places.

Unadjusted LDL Noncontrol

LDL measurements within the preceding 5 years, the maximum interval between measurements recommended by the NCEP,[14] were not retrievable electronically from the EHR for 41.1% of patients. Overall, 14.9% of patients (20,391 of 136,771) with measurements had uncontrolled LDL (Figure 2). The degree of LDL noncontrol varied markedly with patient risk, from 36.1% for patients with CHD or CHD equivalent (highest risk) to 28.3% for patients with no CHD or CHD equivalent but with ≥2 risk factors (intermediate risk), to 6.8% for low-risk patients.

Risk-Adjusted LDL Noncontrol

Variables predictive of LDL noncontrol from a logistic regression model are shown in Appendix Table 5, available online. The c-index for the full model was 0.737; the cumulative c-index for the first 10 variables used for risk-adjustment is 0.734. Online Appendix Figure 2 shows the risk-adjusted percentage of LDL noncontrol by clinic, which varied from 5.8% to 23.6%. The mean noncontrol for all clinics was 13.4%, while the 3 best-performing clinics set the benchmark at 11.2%; 26 of the 33 clinics (79%) had noncontrol rates with 95% confidence intervals higher than this benchmark.

Again, there were marked differences in clinic rank-order based on the nonadjusted rates of noncontrol from that based on the risk-adjusted rate of noncontrol (Figure 4). Six clinics experienced a change in rank order of ≥10 places, whereas 8 clinics changed rank-order between 5 and 10 places and 19 changed rank order ≤4 places. This is due to differences in the distribution of variables predictive of BP and LDL control by clinic (Appendix Tables 4 and 5, available online). Failure to adjust for risk could lead clinics to attribute high rates of noncontrol to the often nonmutable characteristics of their patients (eg, age, sex, and a diagnosis of diabetes) and preclude making changes in processes or structures of care.

Discussion

Key Results

While the EHRs of only 2.2% of patients were missing all BP values within the 2 previous years, 41.1% were missing LDL values within the previous 5 years. Of patients with known values, 16.0% and 14.9% failed to meet guideline recommendations for BP control and LDL control, respectively; however, a large majority of clinics had noncontrol rates in excess of those achieved by the best-performing clinics, indicating substantial room for improvement. Ranking of clinics by risk-adjusted rates of noncontrol was markedly different from ranking by unadjusted rates of noncontrol, indicating the importance of risk adjustment.

Strengths and Limitations

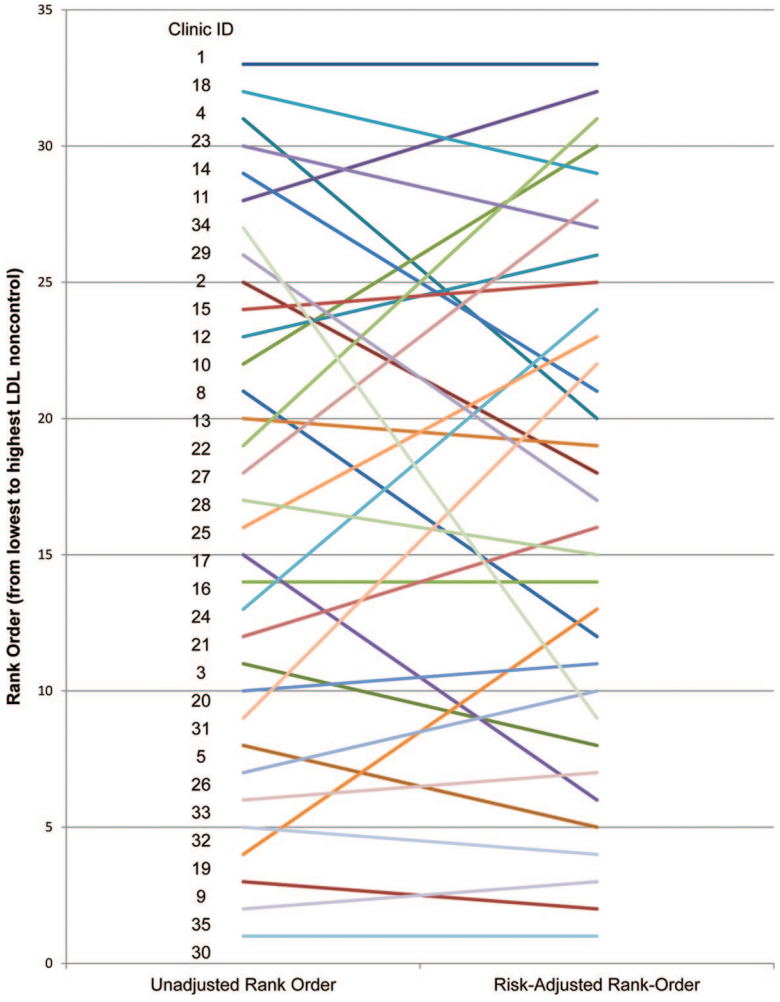
The strengths of this study include the large primary care patient population, the inclusion of all patients within a clinic ≥18 years of age and with ≥1 clinic visit within the preceding 2 years, inexpensive electronic data collection, risk adjustment of the clinic-level outcomes of BP and LDL noncontrol, and the electronic assessment of patient-level noncontrol per JNC7 and NCEP.

Limitations include (1) limited clinic-level data, precluding comparison of characteristics of high and low outlier clinics; 2) incomplete data on race/ethnicity; (3) a large proportion of patients (41.1%) had no LDL measurement within the preceding 5 years retrievable as a discrete data field from the EHR; (4) the participating clinics are not representative of the full range of US ambulatory care; (5) some providers question the validity of EHR data; and (6) the absence of data on MACEs.

Missing LDL Data

The reliability of our assessment of LDL control must be interpreted in light of the fact that 41.1%

Figure 4. Comparison of rank-order of clinics by unadjusted and risk-adjusted low-density lipoprotein (LDL) cholesterol control.



of patients had no LDL value available in a discrete EHR field for the preceding 5 years. We recognize that an LDL value measured at another health care organization may have been recorded as a text note, but we made no attempt to retrieve data from text notes. More important, numeric data buried in a text note is difficult for the care provider or organization to retrieve. A companion article currently under review for publication will report the timeliness of BP and LDL measurements.

Representativeness of the Patient Population

The health care organizations included in this study are not a representative sample of US ambulatory care in the sense that there is no representation of other major models of ambulatory care delivery, such as private integrated systems like Kaiser, government-integrated systems like the Veterans Affairs, and community health centers providing care for the large underserved segment of our population. Although we do not have the data, we believe that DARTNet clinics are at least somewhat representative of private, nonintegrated, fee-for-services clinics. The 33 clinics in this study include urban, academic-affiliated clinics as well as suburban and rural clinics, and they vary in size from a single physician supported by 1 or 2 paraprofessionals to group practices of ≥30 primary care physicians in multiple suburban locations.

Doubts about the Validity of EHR Data

It is our view that the EHR will play an increasingly critical role in both the delivery of health care and the assessment of that delivery. EHRs have an enormous advantage over paper records in cost-effectively aggregating data from large groups of

patients. In a recent supplement of *Medical Care* about electronic data methods, Randhawa and Slutsky,[22] from the Center for Outcomes and Evidence, Agency for Health Care Research and Quality, expressed this view more cogently: "The challenge of addressing complex questions, such as what affects patient outcomes in a real-world clinical setting, demands a scalable electronic infrastructure that can provide high-quality, clinically rich, prospective, multi-site data for generating internally valid and generalizable conclusions in a timely and efficient manner." The current article comes from the DARTNet, which was initially funded by the Agency for Health Care Research and Quality to respond to the challenge posed by Randhawa and Slutsky.

We delivered electronically to the point of care patient-specific clinical decision support, which consisted of graphic displays of BP, LDL, and all antihypertensive and antihyperlipidemic prescriptions over time. In addition, audit and feedback of aggregate clinical data similar to that shown in Figures 1 and 2 and online Appendix Figures 1 and 2 were provided to all care providers on 2 occasions. While our care provider surveys showed that only a minority regularly use these reports, we received virtually no expressions of concern regarding the validity of these data. Before instituting the clinical decision support, these reports were reviewed and approved by our Steering Committee. Our time series assessment of guideline concordance unfortunately showed little change, which we now attribute to our failure to adequately engage the care providers. We are planning to report those data in a separate article.

Data Quality

It is common practice to perform extensive validation of data manually abstracted from paper medical records for clinical research. Validation methods include (1) cross-checking important concepts against several sources of data; (2) checking for illogical data combinations (eg, pregnancy in a male); (3) assessing the accuracy of diagnostic coding by comparing the narrative record against standardized definitions; (4) conducting inter- and intraobserver variability assessments; and (5) excluding unreasonable values in distributions of continuous data. We did only the latter because numbers 1 through 4 above are not routinely performed when working with EHR data since the data as it exists in the EHR is the same data that is being used for clinical decision making; therefore, the practice and provider have a medical/legal obligation for accuracy. Also, laborious and expensive data validation negates an important advantage of EHR data: the ability to inexpensively and quickly collect and analyze data from large numbers of patients. In the context of this study, the ultimate data validation should come in the form of credibility of the results to care providers and improvement of patient outcomes. Finally, in a literature search we were unable to find publications of validation of ambulatory care EHR data against source data.

Use of Electronic Data Collection to Assess Guideline Concordance

We have demonstrated the ability to assess guideline concordance using electronic data collection for 232,172 patients in 33 clinics comprising 10 private, fee-for-service health care organizations with disparate EHRs. Despite daily feedback of patient-specific clinical decision support and 2 cycles of audit and feedback, no credibility issues have been raised by participants in this study.

The costs of data collection and management per patient over 2 years of $2.98 and $4.31, respectively, based on the grant's direct and combined direct and indirect costs, are not intended as a formal cost analysis but as an estimate only. The ultimate value of electronically supported interventions to reduce MACEs must compare the costs of delivery of the intervention to the cost savings from reduced MACEs.

Rates of BP and LDL Noncontrol

The rates of BP and LDL noncontrol in this study are better than those previously reported. The Centers for Disease Control and Prevention,[6] reporting NHANES data from 10,037 adults aged ≥18 years from 2005 to 2008, found that 20.3% (2,108 of 10,037) had uncontrolled hypertension defined as BP ≥140/90 mmHg. We found 16.0% to have uncontrolled BP using the JNC7 definition (<130/80 mmHg for patients with diabetes or chronic kidney disease, <140/90 mmHg otherwise); if we applied the NHANES definition, the noncontrol rate was 13.5%. There are several possible explanations for the lower rates of noncontrol in our study: (1) CRRLC patients are being seen in fee-for-service clinics, meaning that they have a primary care provider and are likely of higher socioeco-

nomic status in contrast to the NHANES sample, which was specifically designed to be representative of the US population. (2) Similarly, the racial/ethnic distribution in our population may be different in a direction favoring better BP control than that of NHANES. (3) BP control may have improved from the time of NHANES data collection (2005–2008) to that of this report (2009–2010).

Reporting NHANES data from 2005 to 2008 and using the same NCEP criteria as we used, the Centers for Disease Control and Prevention[23] also found that 21.2% had uncontrolled LDL, compared with the 14.9% we found. In addition to the caveats for hypertension listed above, 41.1% of our overall population did not have a LDL measurement within 5 years, as recommended by NCEP, and were excluded; this could lead to a large bias in our results.

Risk adjustment of adverse postoperative outcomes in surgery as a quality measure has become common since its introduction more than 2 decades ago.[24–29] Risk-adjusted outcomes as a measure of quality in surgery have been validated against data from site visits[29,30] and are now widely accepted in surgical care. Processes of care (eg, prescribing a statin for patients with CHD), surrogate outcomes (eg, BP and LDL measures), and true outcomes (eg, mortality) are being used increasingly to assess the quality of nonsurgical care. While mortality is often adjusted for patient risk, we have been unable to find published reports in which comparisons of guideline concordance between providers have been adjusted for patient factors associated with concordance. Our multivariable models show that comorbidity has important effects on both BP and LDL control. Clinics with a disproportionate number of these patients may be unfairly ranked higher by unadjusted rates of noncontrol because these risk factors are relatively immutable.

Generalizability

This study should be generalizable to other fee-for-service primary care clinics using EHRs. Care should be taken when applying these results to primary care in other settings, such as integrated health care systems or federally qualified health clinics providing care to the underserved.

Clinical and Research Implications

Although the rates of BP and LDL noncontrol in this study seem to be better than those in reports based on the most recent NHANES data,[6,23] this is not a reason for complacency. The 16.0% of primary care patients with uncontrolled BP and 14.9% with uncontrolled LDL represent substantial opportunities to reduce the morbidity, mortality, and the costs of care due to MACEs. This reduction in mortality, morbidity, and cost of care needs to be demonstrated in a large-scale randomized trial; achieving the large sample size needed (~600,000 patients) will require electronically facilitated data collection and interventions, as we have demonstrated here.

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Appendix Table 1. International Classification of Diseases, Ninth Revision (ICD-9), Code Criteria for Comorbidity and Coronary Heart Disease Risk Factors Used to Construct a Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure (BP) Guideline Concordance Algorithm*

Classification	Disease	ICD-9 Code
I. Higher risk (BP goal <130/80 mmHg)	Diabetes	249.xx, Secondary diabetes mellitus 250.xx, Diabetes mellitus
	Chronic kidney disease	403.xx, Hypertensive chronic kidney disease
		404.xx, Hypertensive heart and chronic kidney disease
		581, Nephrotic syndrome 582, Chronic glomerulonephritis
		585.x, Chronic kidney disease 585, Renal failure, unspecified
		V42, Organ or tissue replaced by transplant:
		V42.0, Kidney
		V45, Other postprocedural states
		V45.1x, Renal dialysis status
		V56.xx, Encounter for dialysis and dialysis catheter care
II. Lower risk (BP goal <140/90 mmHg)	No diabetes diagnoses (see above)	
	No chronic kidney disease diagnoses (see above)	

Data from Chobanian AV, Bakris GL, Black HR, et al. Seventh report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure. Hypertension 2003;42:1205–52 (http://www.nhlbi.nih.gov/guidelines/hypertension/jnc7full.htm); and the 2009 ICD-9-CM (http://icd9 cm.chrisendres.com/).
*See Figure 1.

Appendix Table 2. International Classification of Diseases, Ninth Revision, Code Criteria for Comorbidity and Coronary Heart Disease (CHD) Risk Factors Used to Construct the National Cholesterol Education Program Guideline Concordance Algorithm*

Coronary heart disease	410.xx, Acute myocardial infarction
	411.xx, Other acute and subacute forms of ischemic heart disease
	412, Old myocardial infarction
	413.x, Angina pectoris
	414.xx, Other forms of chronic ischemic heart disease
	429, Ill-defined descriptions and complications of heart disease
	429.7 Certain sequelae of myocardial infarction, not elsewhere classified
	429.71 Acquired cardiac septal defect
	429.79 Other
	V45, Other postprocedural states
	V45.8, Other postprocedural status
	V45.81, Aortocoronary bypass status
	V45.82 Percutaneous transluminal coronary angioplasty status
CHD equivalent	
Diabetes	249.xx, Secondary diabetes mellitus
	250.xx, Diabetes mellitus
	648, Other current conditions in the mother classifiable elsewhere, but complicating pregnancy, childbirth, or the puerperium
	648.0 Diabetes mellitus
Peripheral arterial disease	440.xx, Atherosclerosis
	443, Other peripheral vascular disease
	443.8, Other specified peripheral vascular diseases
	443.81, Peripheral angiopathy in diseases classified elsewhere
	443.9, Peripheral vascular disease, unspecified

Continued

Appendix Table 2. Continued

	444, Arterial embolism and thrombosis
	444.2, Of arteries of the extremities
	444.21, Upper extremity
	444.22, Lower extremity
	445, Atheroembolism
	445.0, Of extremities
	445.01, Upper extremity
	445.02, Lower extremity
Cerebral vascular disease	433.xx, Occlusion and stenosis of precerebral arteries
	434.xx, Occlusion of cerebral arteries
	435.x, Transient cerebral ischemia
	436, Acute, but ill-defined, cerebrovascular disease
	437.x Other and ill-defined cerebrovascular disease
	438.xx, Late effects of cerebrovascular disease
	V12, Personal history of certain other diseases
	V12.5, Diseases of circulatory system
	V12.54, Transient ischemic attack and cerebral infarction without residual deficits
Abdominal aortic aneurysm	441, Aortic aneurysm and dissection
	441.0, Dissection of aorta
	441.02, Abdominal
	441.03, Thoracoabdominal
	441.3, Abdominal aneurysm, ruptured
	441.4, Abdominal aneurysm without mention of rupture
	441.5, Aortic aneurysm of unspecified site, ruptured
	441.6, Thoracoabdominal aneurysm, ruptured
	441.7, Thoracoabdominal aneurysm, without mention of rupture
	441.9, Aortic aneurysm of unspecified site without mention of rupture
Risk factors used in assessing risk category for primary prevention†	
HDL cholesterol	≥60 mg/dL (−1)
Age	Men, ≥45 years; women ≥55 years (1)
Cigarette smoking	Yes (1)
Hypertension	BP ≥140/90 mmHg (average of 2 most recent measurements) or taking antihypertensive medication (1)
Low HDL cholesterol	<40 mg/dL (1)
High HDL cholesterol	≥60 mg/dL (−1)
Family history of premature CHD	CHD in male first-degree relative <55 years old; CHD in female first-degree relative <65 years old (not consistently available in DARTNet) (1)

Data from Ref. 14 or http://www.nhlbi.nih.gov/guidelines/cholesterol/atp3_rpt.htm and the 2009 ICD-9-CM (http://icd9cm.chrisendres.com/).
*See Figure 3.
†In patients without CHD or CHD equivalent. Risk factor score is the sum of bolded numbers in parentheses at end of statements 1–6.
BP, blood pressure; HDL, high-density lipoprotein.

Appendix Table 3. International Classification of Diseases, Ninth Revision (ICD-9), Diagnostic Code Clusters for Morbidity Assessment in Ambulatory Care

No.	Diagnostic/Process Cluster	ICD-9 Codes to Include	
		From	To
1	Hernia (external abdominal)	550	
		551.0	551.2
		552.0	552.2
		553.0	553.2
2	Abdominal pain	789	
3	Acne, diseases of sweat and sebaceous glands	695.3	
		705	705.9
		706.0	706.9
4	Intestinal infectious diseases/ scute gastroenteritis	001	005.9
		006.0	006.2
		007	009
		558.9	
5	Acute sprains, strains	840	848.9
6	Adverse effects of medicinal agents	960	979.9
		995	995.2
		995.4	
7	Alcohol and drug abuse	291	292.9
		303	305.8
		571.0	571.3
		648.3	
8	Allergic reaction	995.3	
9	Allergy treatment/desensitization	V07.1	
		V72.7	
10	Iron deficiency and other deficiency anemias	280	281.9
11	Arrhythmia	427	427.9
		785.0	
12	Asthma	493	493.9
13	Breast lump	611.72	
14	Burns	940	949.9
15	Bursitis, dynovitis, tenosynovitis	726	
		727.00	727.01
		727.04	727.9
		727.2	727.3
16	Cataract, aphakia	366	366.9
		379.3x	
		743.3x	
		998.82	
		V45.61	
17	Cerebral vascular disease/CVA	430	438.9
18	Chest pain	786.5x	
19	Heart failure	428	428.9x
20	Conjunctivitis, keratitis	053.21	
		054.42	054.43
		077	077.9x
		130.1	
		370	370.9
		372	372.3x
21	Contraception	v25.0	v25.9
22	COPD/chronic bronchitis	491	492.9
		494	494.9
		496	496.9
23	Deafness	387	387.9
		388.2	
		389	389.9
24	Degenerative joint disease	715	717.x
25	Depression, anxiety, neuroses (nonpsychotic)	300.0	
		300.4	
		300.5	
		306	
		308	309
		311	
		313	
		799.2	
26	Dermatitis and eczema	690	693.9
		698.2	698.4
		706.3	
27	Dermatophytosis	110	111.9
28	Diabetes mellitus	250	
		648.0	
29	Diaphragmatic hernia	551.3	
		552.3	
		553.3	
30	Disease of hair and hair follicles	704	704.9
31	Diverticular disease	562	
32	Thrombophlebitis, pulmonary embolism	415.1	
		451	
		453	
		673	
		V12.51	V12.52
33	Impacted cerumen (wax in ear)	380.4	
34	Enlarged tonsils	474	
35	Fibrocystic breast disease	610	
36	Fibrositis and myalgia	719.4	719.5
		729.0	729.1
		729.4	729.5
37	Foreign body in eye	930	930.9
		360.5x	360.6
38	Fractures and dislocations	800	839.9
39	Ganglion	727.4x	
40	Gall bladder and biliary tract diseases	574	576.9

Continued

Appendix Table 3. Continued

No.	Diagnostic/Process Cluster	ICD-9 Codes to Include	
		From	To
41	Glaucoma	365	
42	Gout	274	
43	Headache	339	
		346	
		784	
		307.81	
44	Hematuria	599.7x	
45	Helminthiasis, scabies, lice	120	129.9
		132	133.9
46	Hemorrhoids/perirectal disease	455	455.9
		565	566.9
		569	569.4
47	Hepatitis/mononucleosis	070	
		075	
		573.3	
48	Hyperlipidemia	272	272.4
49	Hypertension	401	405.9
		437.2	
		796.2	
50	Infections of eyelid	373	373.2
		373.4	373.6
51	Infertility	606	
		628	
		v26.0	v26.2
		v26.8	v26.9
52	Irritable bowel syndrome	564.1	
		564.5	
53	Ischemic heart disease	410	414.9
		429.7	
		V45.81	
		V45.82	
54	Keratoses	702.0	702.1
55	Lacerations/contusions	530.7	
		618.7	
		620.6	
		622.3	
		623.4	
		624.4	
		664	
		665.3x	665.4
		800.1x	
		800.6x	
		801.1x	
		801.6x	
		803.1x	
		803.6x	
		804.1x	
		804.6x	

Continued

Appendix Table 3. Continued

No.	Diagnostic/Process Cluster	ICD-9 Codes to Include	
		From	To
		851	
		861	
		865	866
		870	887.x
		890	
		891	897.x
		900	904.x
		910	929.x
		950	957.x
		959.x	
		998.2	
56	Low back pain	720	
		721.3	
		721.42	
		722.10	
		722.52	
		724.02	
		724.2	724.3
		724.6	724.7
57	Lymphadenopathy	785.6	
58	Medical and surgical aftercare	V51.0	V55
		V58.7	V58.9
		V67.0	V67.9
59	Menopausal symptoms	256.3x	
		627.2	
		627.4	627.9
60	Menstrual disorders	625.3	625.4
		626	627.1
61	Neoplasm, malignant, involving skin	172	173.9
		232	232.9
62	Neoplasm, malignant, not involving skin	140	165.9
		170	171.9
		174	176.9x
		179	209.x
		230	231.9
		233	234.9
63	Neoplasm, benign	210	229.9
		235	239.9
64	Nonfungal skin infections	607.1	607.2
		680	686.9
65	Obesity	278	
66	Otitis externa	380.1	380.2
67	Otitis media	381	381.4
		382	382.9
		384	384.1
		388.7	
		385.1	
68	Parkinson's disease	332.x	

Continued

Appendix Table 3. Continued

No.	Diagnostic/Process Cluster	ICD-9 Codes to Include	
		From	To
69	Peptic diseases	530.1	530.2
		531	535.9
		530.81	
70	Peripheral neuropathy	354	355.9
		356.1	356.4
		357	357.9
71	Peripheral vascular disease	440.2	440.4
		443.x	
72	Personality disorders	301	301.9
73	Pregnancy and abortion	630.x	633x
		634.x	639.9
		640	646.4
		646.7	646.9
		650	666.x
		670	677.x
		v22.0	v24.9
74	Prostatitis and benign prostatic hypertrophy	600.0	601.9
75	Psoriasis/pityriasis	696	696.9
76	Psychosocial problem	v60.0	v62.9
77	Refractive errors	367.0	367.9
78	Renal calculi	592.0	592.9
79	Respiratory tract infection, acute upper	032.0	034.9
		460	460.9
		462	465.9
		475	475.9
		487.1	487.9
		519.8	
80	Respiratory tract infection, acute lower	466	466.9
		480	488
		490	490.9
81	Rheumatoid diseases	714	714.9
82	Rhinitis, chronic	472.0	
		472.2	
		477	477.9
83	Routine health maintenance	V01.0	V07.0
		V07.2	V07.9
		V20.0	V21.9
		V28.0	V28.9
		V30.0	V37.9
		V39.0	V39.9
		V65.5	
		V70.0	V72.6
		V72.8	V82.9
84	Schizophrenia and affective psychosis	295	298.9
85	Scoliosis/kyphosis	737	737.9
86	Seizure disorder	345	345.9
		780.3	
		779.0	
87	Sexually transmitted diseases	054.1	
		090	99.9
		112.1	112.2
		608	
		614	614.99
		616.x	
88	Sinusitis	461	461.9
		473	473.9
89	Skin ulcer	707	707.9
90	Strabismus	378	378.9
91	Thyroid disease	240	246.9
		648.1	
92	Urethral stricture	598	598.9
		753.6	
93	Urinary tract infection	590	590.9
		595	595.9
		599.0	
		646.5	646.6
		771.82	
		V13.02	
94	Urticaria	708	708.9
		995.1	
95	Uterine prolapse	618.1	618.4
96	Vaginitis	112.1	
		131.00	131.01
		616.1	
		623.5	
		627.3	
97	Valvular heart disease	391.1	
		391.9	
		394	397.9
		424	424.9
98	Varicose veins	454	454.9
99	Vertiginous syndromes	386	386.9
		780.4	
100	Viral exanthem	051	059.x
		74.3	
101	Warts	78.1	
102	Chronic kidney disease	403	404.x
		581	582.x
		585	586
		V42.0	
		V45.11	V45.12
		V56.xx	
103	Abdominal aortic aneurysm	441.xx	

COPD, chronic obstructive pulmonary disorder; CVA, cerebrovascular accident.

Appendix Table 4. Forward Logistic Regression Model of Patient-Level Factors with Blood Pressure Noncontrol per Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure Guideline*

Covariate	Parameter Estimate	*P* Value	Odds Ratio (95% CI)	Cumulative C-Index
Intercept	−3.1521	<.0001		
Hypertension	1.7286	<.0001	5.63 (5.46–5.81)	0.735
Diabetes mellitus	1.5772	<.0001	4.84 (4.64–5.06)	0.764
Body mass index (kg/m^2)				
<18.5 (underweight)	−0.0544	.45	0.95 (0.82–1.09)	0.802
18.5–24.9 (normal)	Reference			
25.0–29.9 (overweight)	0.4171	<.0001	1.52 (1.46–1.58)	0.802
30.0–34.9 (obesity, class I)	0.7208	<.0001	2.06 (1.97–2.14)	0.802
35.0–39.9 (obesity, class II)	0.9440	<.0001	2.57 (2.44–2.71)	0.802
>40.0 (obesity, class III)	1.1896	<.0001	3.29 (3.09–3.50)	0.802
Visits (n)				
1–2	Reference			
3–4	−0.2921	<.0001	0.75 (0.72–0.77)	0.806
5–6	−0.3149	<.0001	0.73 (0.69–0.77)	0.806
>6	−0.3348	<.0001	0.72 (0.68–0.75)	0.806
Age (years)				
18–40	Reference			
41–60	−0.3831	<.0001	1.47 (1.42–1.52)	0.812
61–80	0.6374	<.0001	1.89 (1.81–1.98)	0.812
>80	0.9475	<.0001	2.58 (2.38–2.79)	0.812
Male sex	0.3835	<.0001	1.47 (1.43–1.51)	0.817
Hyperlipidemia	−0.2812	<.0001	0.75 (0.73–0.78)	0.818
Kidney disease, chronic	0.8324	<.0001	2.30 (2.09–2.53)	0.819
Ischemic heart disease	−0.4755	<.0001	0.62 (0.58–0.67)	0.820
Prostatitis and benign prostatic hyperplasia	−0.3367	<.0001	0.71 (0.67–0.76)	0.821

*Number of observations read: 227,123; number of observations used: 209,582.
CI, confidence interval.

Appendix Table 5. Forward Logistic Regression Model of Patient-Level Factors Associated with Low-Density Lipoprotein Cholesterol Noncontrol per the National Cholesterol Education Program Guideline*

Covariate	Parameter Estimate	*P* Value	Odds Ratio (95% CI)	Cumulative C-Index
Intercept	−3.3493	<.0001		
Hyperlipidemia	0.9236	<.0001	2.52 (2.43–2.61)	0.654
Diabetes mellitus	0.8920	<.0001	2.44 (2.33–2.56)	0.682
Body mass index (kg/m^2)				
<18.5 (underweight)	0.0269	.78	1.03 (0.85–1.25)	0.710
18.5–24.9 (normal)	Reference			
25.0–29.9 (overweight)	0.4519	<.0001	1.57 (1.50–1.65)	0.710
30.0–34.9 (obesity, class I)	0.6028	<.0001	1.83 (1.73–1.92)	0.710
35.0–39.9 (obesity, class II)	0.6231	<.0001	1.86 (1.75–1.99)	0.710
≥40.0 (obesity, class III)	0.6632	<.0001	1.94 (1.79–2.10)	0.710
Age (years)				
18–40	Reference			
41–60	0.5888	<.0001	1.80 (1.72–1.89)	0.719
61–80	0.4737	<.0001	1.61 (1.52–1.70)	0.719
>80	0.5006	<.0001	1.65 (1.48–1.83)	0.719
Cerebral vascular disease/CVA	0.9993	<.0001	2.72 (2.49–2.96)	0.726
Male sex	0.2206	<.0001	1.25 (1.20–1.29)	0.731
Visits/year (n)				
1–2	Reference			
3–4	−0.1678	<.0001	0.85 (0.81–0.88)	0.731
5–6	−0.1625	<.0001	0.85 (0.80–0.90)	0.731
>6	−0.2212	<.0001	0.80 (0.76–0.84)	0.731
Alcohol and drug abuse	0.3537	<.0001	1.42 (1.34–1.52)	0.733
Anemia	−0.3073	<.0001	0.74 (0.68–0.79)	0.733
Hypertension	0.1848	<.0001	1.20 (1.16–1.25)	0.734

*Number of observations read: 136,771; number of observations used: 131,589.
CI, confidence interval; CVA, cerebrovascular accident.

Figure A1. Risk-adjusted percentage of patients with uncontrolled blood pressure (BP), by clinic.

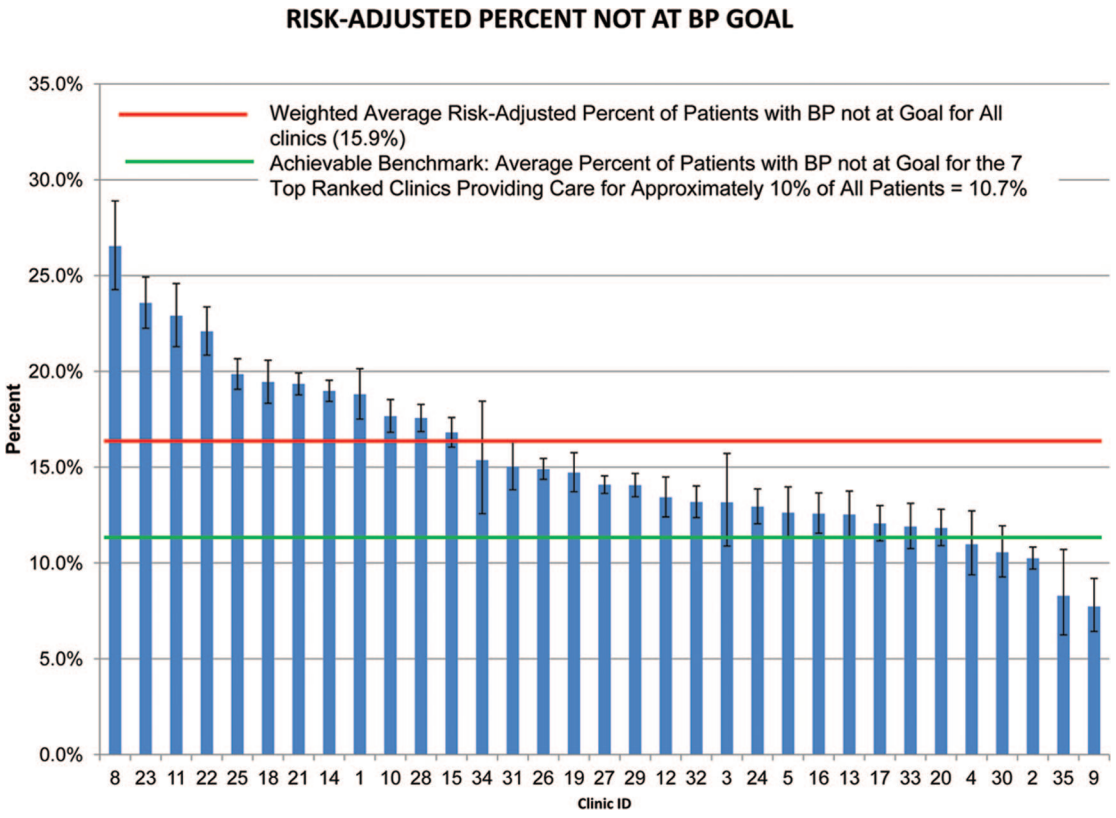

Figure A2. Risk-adjusted percentage of patients with uncontrolled low-density lipoprotein (LDL)-cholesterol, by clinic.