ORIGINAL RESEARCH ARTICLE

Impact of High-Deductible Health Plans on Emergency Department Patients With Nonspecific Chest Pain and Their Subsequent Care

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BACKGROUND: Timely evaluation of acute chest pain is necessary, although most evaluations will not find significant coronary disease. With employers increasingly adopting high-deductible health plans (HDHP), how HDHPs impact subsequent care after an emergency department (ED) diagnosis of nonspecific chest pain is unclear.

METHODS: Using a commercial and Medicare Advantage claims database, we identified members 19 to 63 years old whose employers exclusively offered low-deductible (≤$500) plans in 1 year, then, at an index date, mandated enrollment in HDHPs (≥$1000) for a subsequent year. We matched them with contemporaneous members whose employers only offered low-deductible plans. Primary outcomes included population rates of index ED visits with a principal diagnosis of nonspecific chest pain, admission during index ED visits, and index ED visits followed by noninvasive cardiac testing within 3 and 30 days, coronary revascularization, and acute myocardial infarction hospitalization within 30 days. We performed a cumulative interrupted time-series analysis, comparing changes in annual outcomes between the HDHP and control groups before and after the index date using aggregate-level segmented regression. Members from higher-poverty neighborhoods were a subgroup of interest.

RESULTS: After matching, we included 557 501 members in the HDHP group and 5 861 990 in the control group, with mean ages of 42.0 years, 48% to 49% female, and 67% to 68% non-Hispanic White individuals. Employer-mandated HDHP switches were associated with a relative decrease of 4.3% (95% CI, −5.9 to −2.7; absolute change, −4.5 [95% CI, −6.3 to −2.8] per 10 000 person-years) in nonspecific chest pain ED visits and 11.3% (95% CI, −14.0 to −8.6) decrease (absolute change, −1.7 per 10 000 person-years [95% CI, −2.1 to −1.2]) in visits leading to hospitalization. There was no significant decrease in subsequent noninvasive testing or revascularization procedures. An increase in 30-day acute myocardial infarction admissions was not statistically significant (15.9% [95% CI, −1.0 to 32.7]; absolute change, 0.3 per 10 000 person-years [95% CI, −0.01 to 0.5]) but was significant among members from higher-poverty neighborhoods.

CONCLUSIONS: Employer-mandated HDHP switches were associated with decreased nonspecific chest pain ED visits and hospitalization from these ED visits, but no significant change in post-ED cardiac testing. However, HDHP enrollment was associated with increased 30-day acute myocardial infarction admission after ED diagnosis of nonspecific chest pain among members from higher-poverty neighborhoods.

Key Words: angiography ■ chest pain ■ emergency department ■ insurance ■ myocardial infarction

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Clinical Perspective

What Is New?

- High deductible health plans reduce emergency department visits with a principal diagnosis of nonspecific chest pain (without acute cardiovascular findings or alternative explanations) as well as hospital admissions during these emergency department visits.
- High deductible health plan enrollment was not associated with significant changes in subsequent cardiac testing but was associated with increased 30-day acute myocardial infarction rate after emergency department visits for nonspecific chest pain among patients living in neighborhoods with higher poverty rates.

What Are the Clinical Implications?

- Clinicians evaluating emergency department patients diagnosed with nonspecific chest pain, particularly those with a combination of lower socioeconomic status and high cost-sharing coverage, should account for the likely delays in care that preceded the patients' presentation.
- Clinicians should consider out-of-pocket costs when discussing testing options with patients who experienced acute, nonspecific chest pain, particularly among those with cardiovascular comorbidities who likely have high baseline out-of-pocket expenses.

Nonstandard Abbreviations and Acronyms

CEM	Coarsened exact matching
HDHP	High-deductible health plan

"If you have a medical emergency, *such as chest pain*, please dial 911 or go to the nearest emergency room." This ubiquitous reminder underscores the importance of timely and expedited evaluation for acute chest pain. Each year, up to 7 million patients present to emergency departments (EDs) with chest pain.[1] However, >80% of patients ultimately have no evidence of cardiovascular disease or acute coronary syndrome and no alternative explanation for their pain from the ED evaluation.[2,3] Among these ED patients diagnosed with nonspecific chest pain, there are substantial clinician- and hospital-level variations in the decisions to hospitalize for inpatient evaluation[4–7] and to obtain subsequent functional or anatomic testing, particularly after ED discharge.[8,9] Although admission and subsequent cardiac testing are associated with additional downstream invasive procedures and interventions, many observational studies have not demonstrated associated differences in patient outcomes,[7,8,10,11] calling into question the value of these practices.[12,13]

Insurers and employers increasingly utilize high cost-sharing to disincentivize patients from using costly care. Intended to improve value-seeking by exposing patients to the full cost of care, enrollment in high-deductible health plans (HDHPs) has grown substantially, requiring $1000 to $7000 out-of-pocket spending before coverage for nonpreventive care. By 2020, 57% of US employees were enrolled in plans with a ≥$1000 deductible for single coverage.[14] Research on the impact of HDHPs on acute, unscheduled care is limited. Studies have shown that HDHPs reduce overall ED use, particularly for low-severity conditions.[15,16] Although HDHPs seem to have no significant overall impact on high-severity ED visits,[15,16] 1 study found a decrease in high-severity ED visits in a low socioeconomic status population.[17] Existing research has not explored the effect of HDHPs on ED patients with a diagnosis of nonspecific chest pain, their subsequent hospitalization, cardiac testing, interventions, or downstream outcomes.

In this study, we examined these measures in a national, commercially insured population that experienced employer-mandated HDHP enrollment. We hypothesized that switching into an HDHP would not decrease ED visits for nonspecific chest pain given its high perceived severity but would decrease hospitalization from ED visits, post-ED cardiac testing, and interventions. Furthermore, we hypothesized that 30-day post-ED acute myocardial infarction (AMI) hospitalizations would be unchanged given the lack of association between cardiac care after chest pain ED visits and AMI in previous studies.[7,8,10,11]

METHODS

Dataset

We analyzed 2003 to 2014 data in a large commercial (and Medicare Advantage) claims database. The database included all medical, pharmacy, and hospitalization claims for approximately 48 million members. The dataset also included member enrollment information for those with employer-sponsored insurance. We included only members with employer-sponsored insurance, excluding those with individually purchased insurance to reduce selection bias. This analysis was approved by the institutional review board at the Harvard Pilgrim Health Care Institute with a waiver for informed consent given analysis of deidentified data. All data analyzed in this study were accessed under a data use agreement with the data vendor and cannot be made publicly available. However, all analytic codes and procedures used in this study can be requested from the corresponding author.

The database contained information on plan deductibles for most smaller employers (≤100 employees) but for fewer large employers. Nevertheless, because groups of employees have total annual deductible payments that often reach exact amounts such as $500, $1000, or $2000, we were able to reliably impute deductible levels. The imputation algorithm included a multinomial logistic model to predict deductible

levels on the basis of an enrollee's annual out-of-pocket spending amounts and other aggregated employer characteristics. This algorithm has been previously validated in this database and found to be highly sensitive and specific.[18,19] A more detailed description of the imputation algorithm is available in the Methods in the Data Supplement.

Study Cohort

We identified adults who had at least 2 years of continuous enrollment in the database and were between 19 and 63 years old in the first year. To minimize member self-selection of plan type, we included only members whose employers exclusively offered either a low-deductible plan (annual deductible of ≤$500) or an HDHP (annual deductible of ≥$1000) but not both during each plan-year.

The HDHP group included members who enrolled in low-deductible plans for 12 months (baseline year) followed by 12 months in an HDHP after an employer-mandated switch. The control group included members with at least 24 months of continuous enrollment in a low-deductible plan. We defined the index date as the first day that HDHP group employers mandated HDHP enrollment. Potential index dates for control group employers were the days they renewed their yearly account during their enrollment. If a member (and thus their employer) had multiple potential index dates (for example, 3 consecutive years with a low-deductible plan), we randomly selected one.

Emergency Department Visits for Nonspecific Chest Pain

Consistent with previous observational studies,[7,8,10,11] we examined index ED visits with a primary ED diagnosis of "chest pain, unspecified," "precordial pain," or "other chest pain" (*International Classification of Diseases, Ninth Revision, Clinical Modification* codes 786.50, 786.51, and 786.59, respectively). These diagnoses generally indicate that, after evaluation, the treating clinician did not find significant cardiovascular disease or an alternative explanation for the pain.

We excluded chest pain ED visits with any secondary diagnosis of AMI, pulmonary embolism, aortic disease, or unstable angina because noninvasive cardiac testing is seldom appropriate in these settings. Similarly, we excluded visits with secondary diagnoses of stable angina because this suggests the clinician believed that the chest pain was cardiac-related. We excluded visits with secondary diagnoses of alternative causes of acute noncardiac chest pain such as pneumonia and upper gastrointestinal bleeding. We also excluded chest pain ED visits preceded by any cardiac testing (including stress testing), invasive intervention, or chest pain ED visits in the past 6 months, because the decision to repeat testing is distinct from the decision to pursue follow-up testing without recent evaluation. All conditions and procedures were defined by *International Classification of Diseases, Ninth Revision, Clinical Modification* and Common Procedure Terminology codes detailed in Table I in the Data Supplement.

We included only ED visits from the first 11 months of the baseline and follow-up years to allow for a 30-day follow-up period after the ED visit without plan change.

Outcome Measures

Among the included index ED visits, we identified visits where the patient was hospitalized (hereafter referred to as index ED hospitalizations) or were followed by noninvasive cardiac testing within 3 days, including stress ECG, stress nuclear myocardial perfusion scan, stress echocardiogram, and coronary computed tomography angiogram (Table I in the Data Supplement). In addition, using a 30-day post-ED visit window, we identified patients experiencing noninvasive cardiac testing, invasive coronary angiography, revascularization procedures (including coronary stenting and coronary artery bypass grafting), and AMI inpatient admissions (defined by the principal discharge diagnosis of an inpatient episode; Table I in the Data Supplement). We used the subsets of index ED visits followed by the outcomes of interest as the numerator when calculating outcome rates. For example, any noninvasive test in 3 days refers to the number of ED visits with a principal ED diagnosis of nonspecific chest pain followed by any noninvasive cardiac testing in 3 days.

For all outcomes, we used the universe of included members as the denominator instead of chest pain ED visits. This decision was based on previous studies showing that HDHP switches disproportionately reduce low-severity ED visits without significant changes in high-severity visits.[15,17] Therefore, using chest pain ED visits as the denominator could lead to the conclusion that ED visits increased in severity even when high-severity ED visits experienced little change. However, visit-level analyses can still provide intuitive insights about changes per visit. We therefore also performed secondary visit-level analyses, using chest pain ED visits as the denominator, to examine for consistency with our primary conclusions.

Covariates

We used version 10 of the Johns Hopkins ACG System to calculate members' baseline year comorbidity score and categorized members into 5 levels by quintiles of their comorbidity scores.[20] Using validated census-based measures,[21] we derived proxy demographic measures from American Community Survey 5-year estimates from 2008 to 2012 at the census tract level linked to each member's most recent residential address provided by the data vendor. Through this approach, we classified members' neighborhoods by poverty levels (<5%, 5%–9.9%, 10%–19.9%, and ≥20% of residents living below the federal poverty level) and education levels (<15%, 15%–24.9%, 25%–39.9%, and ≥40% of residents with less than a high school education). We categorized members' neighborhood as predominantly Black, White, or Hispanic if they lived in a census block group with ≥75% population reported as the corresponding racial/ethnic group. We further categorized members as Hispanic or Asian using the E-Tech system (Ethnic Technologies), which analyzes full names and geographic locations of individuals.[22,23] We categorized members who did not fit into these categories as living in mixed race-ethnicity neighborhoods. We classified members by age (19–29, 30–39, 40–49, and 50–64 years), sex, census US region (West, Midwest, South, or Northeast), and employer size (0–49, 50–99, 100–249, 250–499, 500–999, or ≥1000 employees). We also calculated the total number of ED visits, inpatient episodes, outpatient medical visits, and mental health

visits in the baseline year as a proxy for members' baseline medical needs and use.

Study Design and Matching

We applied a before-after with control group study design. We performed a population-level match to simulate an experiment in which 1 of 2 equivalent groups was exposed to HDHPs. We calculated the employer propensity to switch to an HDHP and the member propensity to be used by such an employer. The propensity models included aggregated employer-level characteristics (such as employer size, census region, proportion of employees by demographic characteristics, and baseline expenditures) and member characteristics, including member sociodemographic covariates, baseline comorbid cardiovascular conditions, and health care expenses. Both propensity models also included baseline year annual outcome rates. The member level model further included quarterly outcomes for ED visits for nonspecific chest pain and any stress test in 3 days. We then exact-matched control group members to HDHP group members on terciles of employer and member propensity scores for the HDHP switch, employer size, member-level baseline year out-of-pocket costs ($0–$250; $250–$1000; $1000–$2500; >$2500), and tercile of employer-level ratio of out-of-pocket cost to total standardized costs. We also exact-matched on several baseline year outcomes, including nonspecific chest pain ED visits, hospitalization during index ED visits, any stress test in 3 days, revascularization in 30 days, and AMI admission in 30 days. Matching on baseline outcome measures before HDHP switch has been shown to help reduce unmeasured imbalances[24,25] and selection bias where employers with higher baseline spending were more likely to switch to HDHP (Table II in the Data Supplement). We used coarsened exact matching (CEM), a method that creates a weight with the proportion of persons in each specified stratum to adjust for the differences

between study groups.[26,27] We detailed the propensity model specifications, exact-matched variables, and the rationale for these choices in the Methods in the Data Supplement. The study cohort CONSORT diagram (Consolidated Standards of Reporting Trials) is provided in Figure 1.

Statistical Analysis

We calculated baseline characteristics of the HDHP and control groups before and after matching, comparing the groups using standardized mean differences.[28]

We analyzed cumulative outcome measures in an interrupted time-series design framework,[29–31] comparing changes in annual outcome rates from baseline to follow-up years between the HDHP group and the matched control group. We first calculated monthly cumulative outcome rates for the HDHP and matched control groups before and after the index date using CEM weights to account for prematching imbalances in observed covariates. We plotted them to provide visualization of changes in uncommon outcomes (subgroups of index ED visits with each outcome) over time. Consistent with its visual interpretation, we applied aggregate-level segmented regression models to the monthly cumulative outcome rates. We used generalized linear models including an intercept, a baseline continuous monthly trend, a trend change, a quadratic trend change (to account for any monthly change in the follow-up year trend), and their interaction with an indicator for HDHP group, using robust SEs accounting for first-degree autocorrelation. Using marginal effects methods,[32] we estimated outcome rates at the end of the baseline and follow-up years and calculated the absolute and relative changes in the HDHP group versus the matched control group.

We tested 2 alternative modeling approaches to demonstrate the stability of our estimates. In the primary analysis, we directly calculated cumulative outcome rates in HDHP and matched control groups without adjusting for covariates because, after
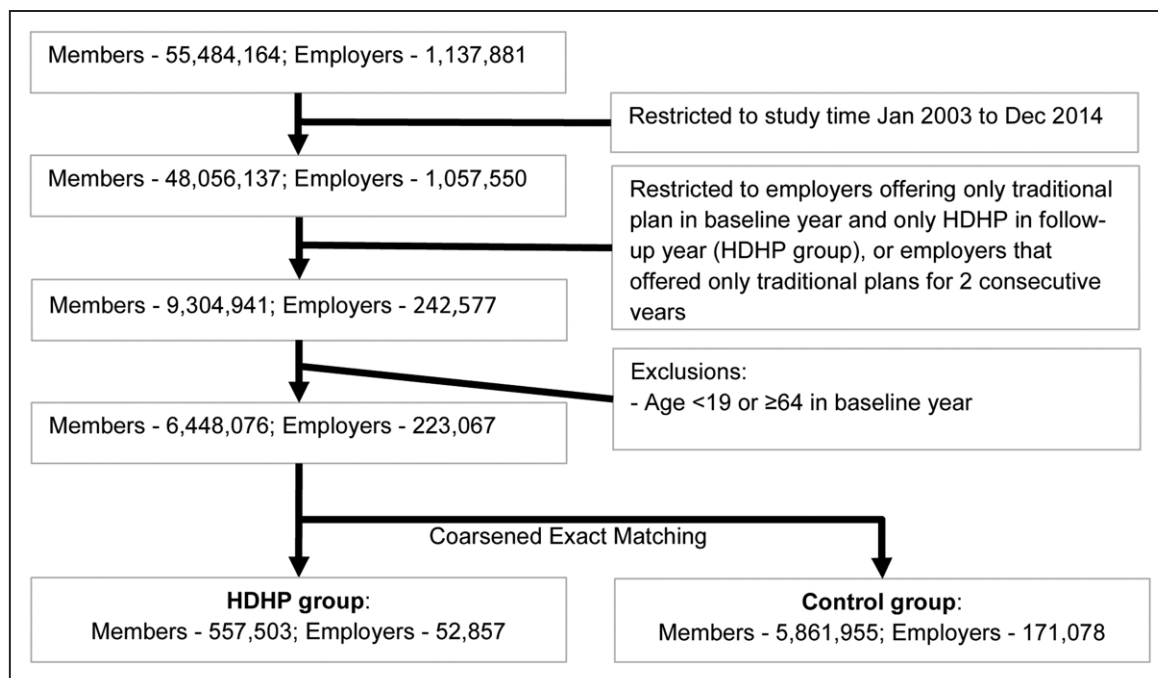

Figure 1. CONSORT diagram of study cohort selection.
HDHP indicates high-deductible health plan.

applying CEM weights, we were able to achieve good balance between the 2 groups across the observable characteristics. To test its robustness, we performed sensitivity analysis by adjusting for several covariates that were still marginally imbalanced with standardized mean differences of >0.05. We first calculated adjusted monthly outcome rates using a generalized estimating equation with negative binomial distribution and log link, accounting for person-level clustering. The model adjusted for calendar year of the index dates (when HDHP switch occurred), US census 4 regions, and member age, incorporating CEM weights. We then calculated cumulative adjusted monthly rates from these adjusted monthly outcome rates and applied aggregate-level segmented regression as above.

We also performed a visit-level analysis using a difference-in-differences approach. We constructed a dataset with each row of data representing an ED visit and we included the corresponding baseline year member and employer characteristics. We utilized CEM-weighted logistic regression with member-level clustered robust SEs to model the probability of subsequent outcomes to the chest pain ED visits. The model included an indicator for HDHP or control group, an indicator for baseline versus follow-up year, and the interaction of the 2 variables, adjusting for member and employer characteristics included in the member-level propensity model. We used marginal estimation methods to calculate the estimated absolute and relative changes in outcome rates per visit.

We used SAS 9.4 and Stata/MP 15.0 for all analyses.

Subgroup Analyses

We replicated the primary analyses in several subgroups to elicit potential drivers of HDHP's effect. First, we exact-matched and stratified the study population by the presence of any cardiovascular comorbidities and risk factors in the baseline year including coronary artery disease, hypertension, and hyperlipidemia (Table I in the Data Supplement) because cardiac testing may predominantly occur among members with existing cardiovascular risk factors. Second, because high out-of-pocket costs may disproportionately impact lower-income members, we exact-matched and stratified members by neighborhood poverty rate above or below 10%. Third, we examined the effect of different deductible levels on our outcome measures. To do so, we distinguished HDHP group employers mandating switches to HDHPs with deductibles between $1000 and $2500, and deductibles of ≥$2500, comparing them with respectively matched control groups. Fourth, we examined the effect of the HDHP switch on cardiac testing when only considering index nonspecific chest pain ED visits where the patient was not hospitalized, because existing guidelines primarily address follow-up cardiac testing among patients who were not admitted.[33,34] Last, we examined hospitalized care among patients who were admitted after receiving an ED diagnosis of nonspecific chest pain. We measured the rate of noninvasive testing, invasive angiography, and revascularization during index ED hospitalizations as well as a primary diagnosis of AMI at discharge from these hospitalizations.

RESULTS

After matching, we included 557 503 members used by 52 857 employers in the HDHP group and 5 861 955 members used by 171 078 employers in the control group. Matching reduced observed imbalances between the 2 groups (Table 1, Table III in the Data Supplement), with mean ages of approximately 42 years, 48% to 49% female, 67% non-Hispanic White individuals, 17% living in neighborhoods with ≥20% of residents below the federal poverty level, and 26% to 27% living in neighborhoods with ≥15% of residents with below high school education attainment. Baseline out-of-pocket spending trends among HDHP and control members were similar after matching, but there was a relative increase of approximately 33% in the HDHP group in the follow-up year (Figure I in the Data Supplement).

There were 133 121 ED visits for nonspecific chest pain included in the study period. Employer-mandated HDHP switches were associated with a 4.3% (95% CI, −5.9 to −2.7) relative decrease (absolute change, −4.5 per 10 000 person-years [95% CI, −6.3 to −2.8]) in nonspecific chest pain ED visits and an 11.3% (95% CI, −14.0 to −8.6) relative decrease (absolute change, −1.7 per 10 000 person-years [95% CI, −2.1 to −1.2]) in index ED hospitalizations (Table 2, Figure 2). The HDHP switch was not associated with significant changes in stress testing at 3 or 30 days after the index nonspecific chest pain ED visit except for the nuclear stress test (−15.2% [95% CI, −21.5 to −8.9]; absolute change, −0.8 per 10 000 person-years [95% CI, −1.1 to −0.4]; Figure 2). In the 30 days after the index nonspecific chest pain ED visits, the HDHP switch was associated with an 8.2% (95% CI, −12.0 to −4.5) relative decrease (absolute change, −0.8 per 10 000 person-years [95% CI, −1.2 to −0.4]) in invasive angiography. The increase in AMI admissions in the 30 days after nonspecific chest pain ED visits was not statistically significant (15.9% [95% CI, −1.0 to 32.7]; absolute change, 0.3 per 10 000 person-years [95% CI, −0.01 to 0.5]; P=0.065; Figure 3). In visit-level analyses, we found similar direction and magnitude in point estimates, but they did not reach statistical significance (Table IV in the Data Supplement). Adjusting monthly cumulative outcomes for covariates did not change our findings (Table V in the Data Supplement).

When stratified by the presence of baseline cardiovascular comorbidities, members with comorbidities accounted for most of the decrease in nonspecific chest pain ED visits (−8.9% [95% CI, −14.5 to −3.3]; absolute change, −15.6 per 10 000 person-years [95% CI, −26.1 to −5.1]) as well as index ED hospitalizations (−18.1% [95% CI, −26.3 to −10.0]; absolute change, −5.5 per 10 000 person-years [95% CI, −8.3 to −2.6]; Table 3). Although there were no significant changes in noninvasive testing, both invasive angiography (−19.7% [95% CI, −32.4 to −6.9]; absolute change, −4.6 per 10 000 person-years [95% CI, −8.4 to −0.9]) and revascularization (−22.5% [95% CI, −41.8 to −3.2]; absolute change, −2.6 per 10 000 person-years [95% CI, −5.0 to −0.2]) declined after the HDHP switch among members with baseline year comorbidities. However, these members

Table 1. Characteristics of Study Cohort, Before and After Matching

Study group	Unmatched					Matched				
	HDHP		Control			HDHP		Control		
					SMD§			Weighted N		SDM§
Sample size	557 707		5 881 410			557 503		5 861 955		
Employer size, No. (%)										
0–49	249 817	(44.8)	753 441	(12.8)	1.311	249 744	(44.8)	2 625 973	(44.8)	0.000
50–99	102 711	(18.4)	407 879	(6.9)		102 652	(18.4)	1 079 351	(18.4)	
100–249	108 325	(19.4)	723 430	(12.3)		108 286	(19.4)	1 138 591	(19.4)	
250–499	42 379	(7.6)	629 222	(10.7)		42 360	(7.6)	445 401	(7.6)	
500–999	29 479	(5.3)	607 097	(10.3)		29 473	(5.3)	309 899	(5.3)	
≥1000	24 996	(4.5)	2 760 341	(46.9)		24 988	(4.5)	262 740	(4.5)	
Female, No. (%)	270 625	(48.5)	3 004 915	(51.1)	−0.051	270 533	(48.5)	2 855 943	(48.7)	−0.004
Age in years, No. (%)					0.058					0.051
19–29	96 129	(17.2)	1 114 590	(19.0)		96 121	(17.2)	1 075 029	(18.3)	
30–39	122 076	(21.9)	1 381 090	(23.5)		122 048	(21.9)	1 326 205	(22.6)	
40–49	157 988	(28.3)	1 590 759	(27.0)		157 922	(28.3)	1 619 182	(27.6)	
50–64	181 514	(32.5)	1 794 971	(30.5)		181 412	(32.5)	1 841 539	(31.4)	
Neighborhood poverty level,* No. (%)					0.05					0.000
<5%	136 800	(24.5)	1 606 129	(27.3)		136 757	(24.5)	1 468 103	(25.0)	
5%–9.9%	153 522	(27.5)	1 634 418	(27.8)		153 471	(27.5)	1 626 396	(27.7)	
10%–19.9%	169 720	(30.4)	1 686 158	(28.7)		169 654	(30.4)	1 768 131	(30.2)	
≥20%	97 665	(17.5)	954 705	(16.2)		97 621	(17.5)	999 324	(17.0)	
Neighborhood education level,† No. (%)					0.027					0.027
<15%	408 491	(73.2)	4 371 448	(74.3)		408 354	(73.2)	4 329 555	(73.9)	
15%–24.9%	97 618	(17.5)	997 220	(17.0)		97 580	(17.5)	1 019 293	(17.4)	
25%–39.9%	40 807	(7.3)	413 186	(7.0)		40 782	(7.3)	410 513	(7.0)	
≥40%	10 791	(1.9)	99 556	(1.7)		10 787	(1.9)	102 594	(1.8)	
Race/ethnicity, No. (%)					0.134					0.026
Hispanic	50 922	(9.1)	560 683	(9.5)		50 909	(9.1)	509 594	(8.7)	
Asian	15 236	(2.7)	245 768	(4.2)		15 232	(2.7)	165 734	(2.8)	
Black neighborhood	9520	(1.7)	148 253	(2.5)		9513	(1.7)	101 202	(1.7)	
Mixed neighborhood	107 122	(19.2)	1 307 655	(22.2)		107 075	(19.2)	1 146 948	(19.6)	
White neighborhood	374 907	(67.2)	3 619 051	(61.5)		374 774	(67.2)	3 938 476	(67.2)	
United States region, No. (%)					0.253					0.065
West	64 973	(11.7)	861 081	(14.6)		64 951	(11.7)	752 589	(12.8)	
South	261 545	(46.9)	2 539 493	(43.2)		261 448	(46.9)	2 637 228	(45.0)	
Midwest	193 157	(34.6)	1 725 322	(29.3)		193 085	(34.6)	2 033 655	(34.7)	
Northeast	38 032	(6.8)	755 514	(12.8)		38 019	(6.8)	438 483	(7.5)	
Annual out-of-pocket cost, $, mean (SD)	625.35	(1120.35)	520.51	(937.64)	0.101	624.70	(1119.46)	623.38	(1096.64)	0.001
ACG comorbidity score, mean (SD)‡	0.82	(1.46)	0.83	(1.47)	−0.008	0.82	(1.46)	0.83	(1.44)	−0.006

Additional study cohort characteristics available in Table III in the Data Supplement. HDHP indicates high-deductible health plan; and SMD, standardized mean difference.

*Living in neighborhoods with percent population below poverty level.

†Living in neighborhoods with percent population below high school education levels.

‡ACG comorbidity score of 1.0 is the mean score of the reference population that represent the general US population.

§Standardized mean difference of <0.2 indicates minimal difference.

Table 2. ED Visits per 10 000 Person-Years for HDHP and Control Group at Baseline and Follow-Up Years

Study year	HDHP (n=557 503)		Control (n=5 861 955)		Absolute change (95% CI)	Relative % change (95% CI)	P value
	Baseline	Follow-up	Baseline	Follow-up			
Nonspecific chest pain ED visits*	95.9	101.0	96.3	105.7	−4.5 (−6.3 to −2.8)	−4.3 (−5.9 to −2.7)	<0.001
ED hospitalizations†	12.8	13.1	12.6	14.2	−1.7 (−2.1 to −1.2)	−11.3 (−14.0 to −8.6)	<0.001
Three-day outcomes							
Any noninvasive test‡	26.9	28.3	27.0	29.0	−0.8 (−1.9 to 0.4)	−2.7 (−6.5 to 1.2)	0.174
Stress ECG	18.5	19.0	18.4	19.0	−0.1 (−0.8 to 0.5)	−0.7 (−4.1 to 2.6)	0.669
Nuclear stress	3.9	4.3	3.9	5.0	−0.8 (−1.1 to −0.4)	−15.2 (−21.5 to −8.9)	<0.001
Stress echo	4.3	4.8	4.5	4.8	0.2 (−0.2 to 0.6)	4.6 (−5.3 to 14.5)	0.361
30-Day Outcomes							
Any noninvasive test‡	37.2	39.1	37.6	40.6	−0.8 (−2.2 to 0.5)	−2.0 (−5.3 to 1.3)	0.235
Invasive angiography	8.5	8.8	8.6	9.7	−0.8 (−1.2 to −0.4)	−8.2 (−12.0 to −4.5)	<0.001
Revascularization	3.0	3.6	3.1	3.8	−0.1 (−0.4 to 0.2)	−2.8 (−11.4 to 5.8)	0.521
AMI Admission	1.1	2.0	1.1	1.6	0.3 (−0.01 to 0.5)	15.9 (−1.0 to 32.7)	0.065

AMI indicates acute myocardial infarction; echo, echocardiogram; ED, emergency department; and HDHP, high-deductible health plan.

*Chest pain ED visits included index ED visits with a principal diagnosis of nonspecific chest pain.

†Inpatient hospitalization as a result of the ED evaluation (admitted from the index nonspecific chest pain ED visit).

‡Any noninvasive test includes stress ECG, nuclear stress imaging, stress echocardiogram, and coronary computed tomographic angiogram.

did not experience significant increase in the rate of 30-day post-ED AMI admission.

When stratified by neighborhood poverty rates, members living in higher-poverty neighborhoods accounted for most of the reduction in nonspecific chest pain ED visits (−7.3% [95% CI, −8.3 to −6.3]; absolute change, −8.7 per 10 000 person-years [95% CI, −10.0 to 7.4]) and index ED hospitalizations (−15.7% [95% CI, −19.2 to −12.3]; absolute change, −2.8 per 10 000 person-years [95% CI, −3.4 to −2.1]; Table 4). The HDHP switch was also associated with an increase of AMI hospitalization in the 30 days after ED visit for nonspecific chest pain by 29.4% (95% CI, 13.3 to 45.6; absolute change, 0.6 per 10 000 person-years [95% CI, 0.3 to 0.9]).

When we compared the control group to HDHP group members with different follow-up year deductible levels, larger deductible increases were associated with larger reductions in index ED hospitalizations (−37.1% [95% CI, −44.1 to −30.0] versus −4.8% [95% CI, −8.0 to −1.5]), invasive angiography (−33.3% [95% CI, −43.1 to −23.4] versus −3.5% [95% CI, −8.1 to 1.2]), and revascularization procedures (−41.5% [95% CI, −57.1 to −26.0] versus 1.5% [95% CI, −8.0 to 11.0]) in 30 days after index ED visits (Table VI in the Data Supplement).

When only considering nonspecific chest pain ED visits where patients were discharged, there were decreases in invasive angiography at 30 days after these index ED visits, but no change in noninvasive testing at 3 or 30 days or 30-day AMI admissions (Table VII in the Data Supplement). However, when we examined patients who were hospitalized after ED diagnosis of nonspecific chest pain (index ED hospitalizations), there were significant reductions in noninvasive testing and invasive angiography

during the associated hospitalization, but an increase in principal diagnosis of AMI (20.5% [95% CI, 1.0 to 40.1]; absolute change, 0.3 per 10 000 person-years [95% CI, 0.05 to 0.5]; Table 5) at hospital discharge.

DISCUSSION

In this study, we found that members whose employers mandated HDHP switches had reduced index ED visits with a diagnosis of nonspecific chest pain. Subgroup analyses suggested that members with baseline year cardiovascular comorbidities and those with higher neighborhood poverty rates accounted for most of the observed reduction. Our findings are consistent with previous research. For example, studies have found that although increased cost-sharing reduces low-severity ED visits substantially,[15,16] it can also decrease intermediate- and high-severity ED visits,[35,36] particularly among vulnerable populations.[17] A recent analysis using the same database also found that HDHP switches were associated with delayed evaluation for cardiovascular symptoms.[18]

The HDHP switch was associated with a significant reduction in hospitalization from index ED visits after an ED diagnosis of nonspecific chest pain. The relative decrease was measurably larger than the relative decrease in index ED visits, suggesting that HDHP enrollment influenced decisions to hospitalize during index ED visits. We also found that the reduction in index ED hospitalizations was greater among members living in neighborhoods with higher poverty rates and those with ≥$2500 deductibles, suggesting that the reduction in index ED hospitalizations was driven by out-of-pocket disincentives. Our finding is consistent with a previous
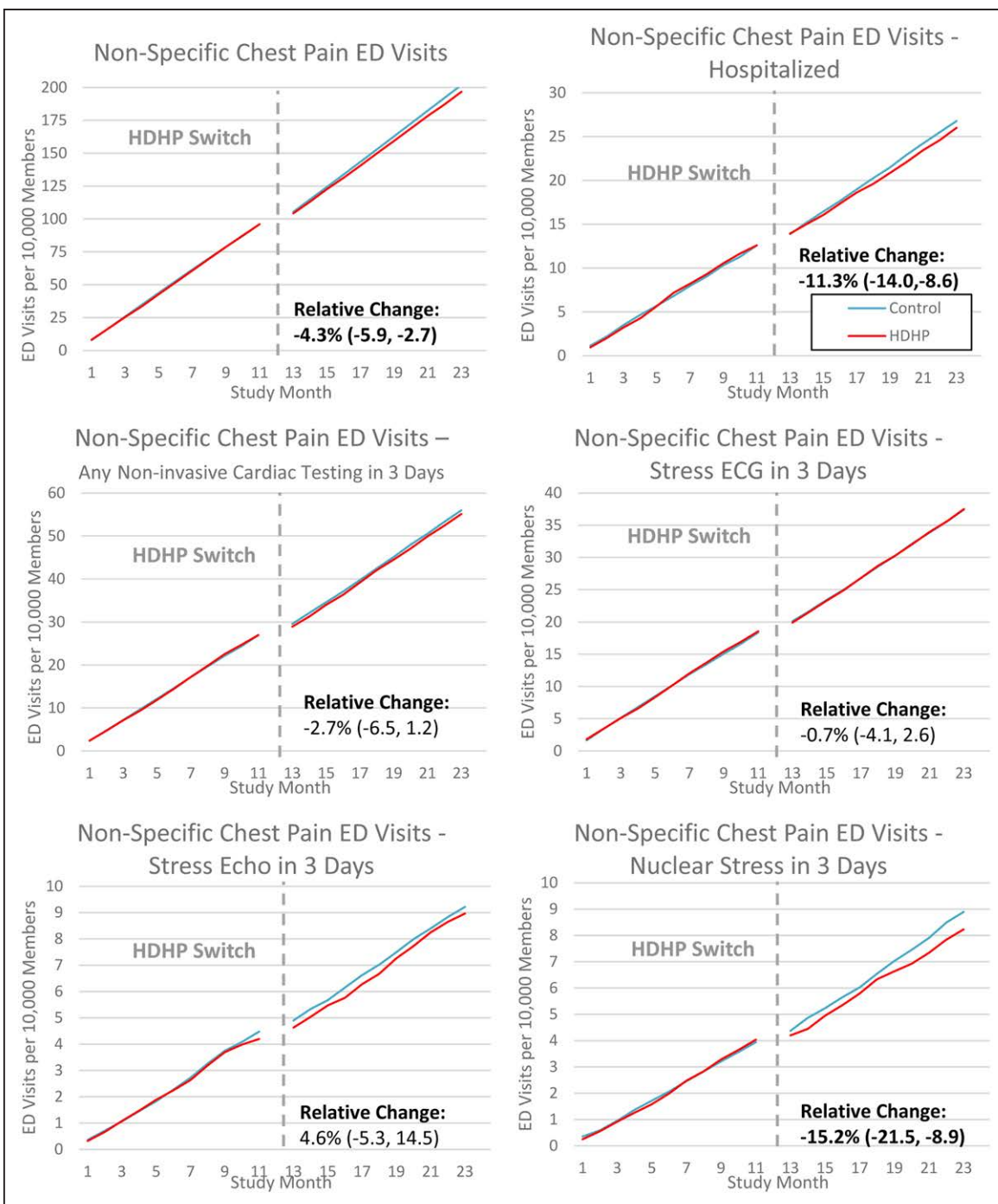
Figure 2. Cumulative monthly outcome rates, comparing the HDHP and the matched control groups.
Relative change refers to percent change in annual outcome in HDHP vs matched control group. Values in parentheses are 95% CI. Echo indicates echocardiogram; ED, emergency department; and HDHP, high-deductible health plan.

study that found fewer hospitalizations from ED visits after HDHP enrollment.[15]

In contrast, the associations between HDHP enrollment and changes in cardiac testing and interventions were less consistent. There were no significant changes in noninvasive testing, except nuclear stress tests or revascularization procedures after nonspecific chest pain ED visits. Although there was a significant reduction in invasive angiography

after the HDHP switches, it was proportional to the decline in ED visits for nonspecific chest pain, suggesting that the decrease in the index ED visits accounted for most of the changes in testing. These findings were consistent in the stratified analyses by baseline cardiovascular comorbidities and when only considering index ED visits where patients were discharged. When we examined index ED hospitalizations, the decreases in noninvasive testing and invasive
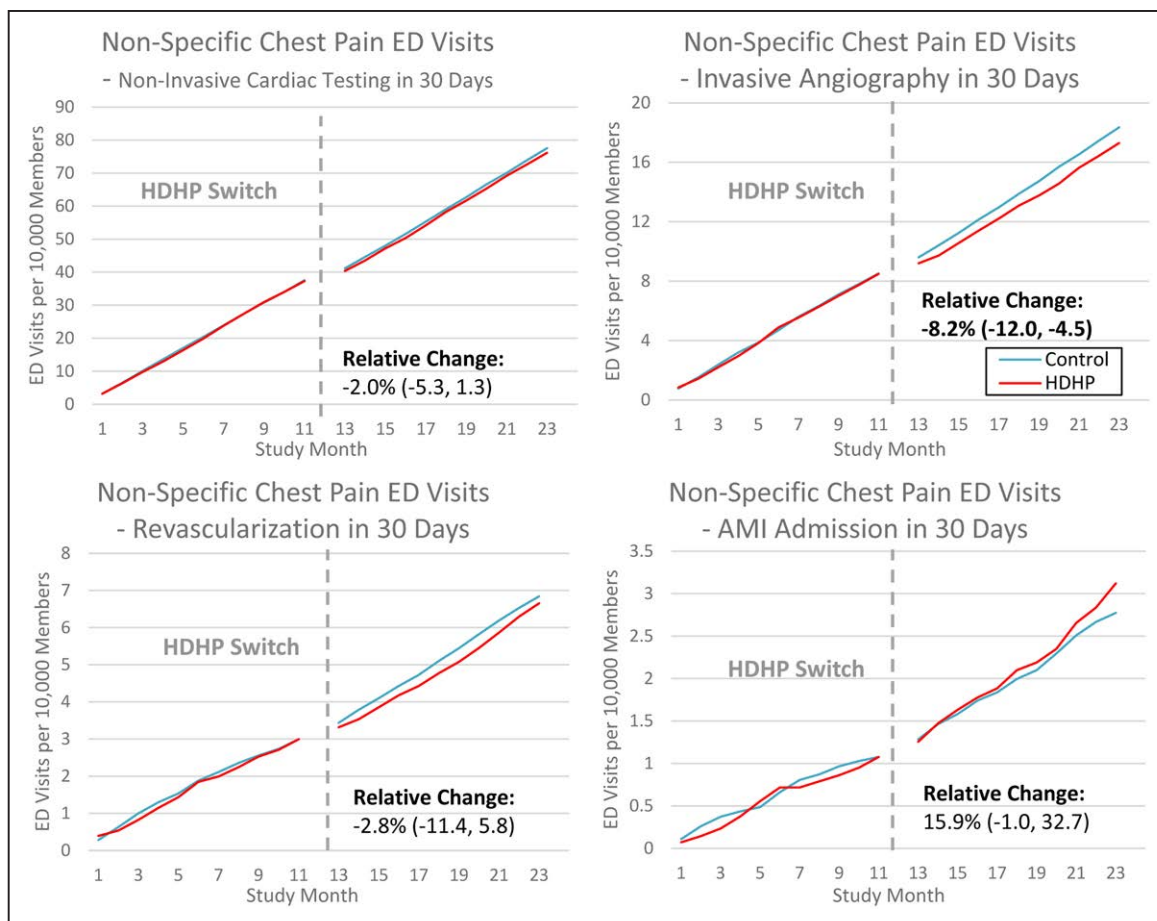
Figure 3. Cumulative monthly 30-day outcome rates comparing the HDHP group and the matched control group. Relative change refers to percent change in annual outcome in HDHP vs matched control group.
Values in parentheses are 95% CI. AMI indicates acute myocardial infarction; ED, emergency department; and HDHP, high-deductible health plan.

angiography during admission after ED diagnosis of non-specific chest pain were also proportional to the decrease in index ED hospitalizations. Our recent analysis on ED low-value diagnostic imaging found similar patterns where the reduction in index ED visits accounted for population-level changes in ED low-value imaging use.[37] Previous studies have also shown the limited impact of increased cost-sharing on within-visit decisions on diagnostic testing.[38,39] Although a recent study found delayed cardiac testing and treatment among patients with diabetes,[18] these likely occurred in the context of fewer specialist visits or acute care encounters.[19]

We did not find a statistically significant increase in 30-day post-ED AMI admissions after HDHP switches. However, the point estimate in our primary analysis approached significance ($P=0.065$), and the increase in 30-day post-ED AMI admission among members living in neighborhoods with higher poverty rates was statistically significant. Therefore, there is likely a meaningful association between HDHP enrollment and increased AMI admissions after ED diagnosis of nonspecific chest pain that we could not detect in our primary analysis because of limitations in event rates and statistical power.

The associated increase in AMI admission after HDHP enrollment appeared to be driven by patients hospitalized after a diagnosis of nonspecific chest pain in the index ED visit who later received an inpatient diagnosis of AMI. In contrast, there were no significant changes in 30-day AMI admissions among patients discharged from index ED visits, despite a decrease in cardiac testing, consistent with past observational studies.[8,10,11] These observations indicated that the increase in AMI admissions after an ED diagnosis of nonspecific chest pain was likely influenced by factors preceding the index ED visits.

One possibility is that HDHP members deferred outpatient evaluations or ED visits for concerning cardiovascular symptoms that might have prevented downstream AMI.[18] As a result, there is a delayed increase in ED visits for nonspecific chest pain with AMI diagnosis after patients were hospitalized. In visualizing the monthly cumulative rates of 30-day post-ED AMI admission (Figure 3), the increase in this outcome in the HDHP group came toward the end of the follow-up year. This pattern of delayed increase in higher severity presentation was similarly observed in a study

Table 3. ED Visits per 10 000 Person-Years for HDHP and Control Group at Baseline and Follow-Up Years, Stratified by Presence of Baseline Year Cardiovascular Comorbidities

	No cardiovascular comorbid conditions					Has cardiovascular comorbidities				
	Baseline		Absolute change	Relative % change	P value	Baseline		Absolute change	Relative % change	P value
	HDHP	Control				HDHP	Control			
Nonspecific chest pain ED visit*	37.7	37.0	1.9 (−1.6 to 5.5)	2.7 (−2.3 to 7.7)	0.292	216.9	217.9	−15.6 (−26.1 to −5.1)	−8.9 (−14.5 to −3.3)	0.002
ED hospitalization†	1.1	1.1	0.7 (−0.5 to 1.9)	9.6 (−7.8 to 27.1)	0.278	37.0	36.5	−5.5 (−8.3 to −2.6)	−18.1 (−26.3 to −10.0)	<0.001
Three-day outcomes										
Any noninvasive test‡	5.2	4.9	1.5 (−0.02 to 2.9)	8.4 (−0.1 to 16.9)	0.053	71.5	71.9	−3.4 (−9.4 to 2.6)	−6.5 (−17.5 to 4.5)	0.246
Stress ECG	3.3	3.3	2.0 (1.2 to 2.8)	17.9 (9.5 to 26.3)	<0.001	49.6	49.6	−3.3 (−6.9 to 0.3)	−9.2 (−18.7 to 0.3)	0.056
Nuclear stress	0.4	0.5	−0.3 (−0.6 to −0.02)	−11.4 (−21.2 to −1.6)	0.023	11.0	11.1	−1.3 (−2.7 to −0.05)	−13.7 (−26.6 to −0.9)	0.036
Stress echo	1.2	1.3	−0.1 (−0.5 to 0.4)	−2.3 (−14.3 to 9.7)	0.707	10.6	10.9	0.8 (−0.8 to 2.5)	12.8 (−15.1 to 40.8)	0.368
Thirty-day outcomes										
Any noninvasive test‡	7.4	7.8	1.7 (−0.4 to 3.8)	6.9 (−1.9 to 15.7)	0.125	98.1	98.9	−4.3 (−12.0 to 3.4)	−6.1 (−16.5 to 4.4)	0.255
Invasive angiography	0.4	0.4	0.3 (−0.2 to 0.9)	7.2 (−5.6 to 20.0)	0.27	30.0	28.9	−4.6 (−8.4 to −0.9)	−19.7 (−32.4 to −6.9)	0.002
Revascularization	0.1	0.1	0.3 (−0.1 to 0.7)	17.8 (−5.9 to 41.6)	0.141	12.6	10.9	−2.6 (−5.0 to −0.2)	−22.5 (−41.8 to −3.2)	0.022
AMI admission	0.05	0.05	0.3 (0.1 to 0.5)	30.2 (6.0 to 54.4)	0.015	3.4	3.5	0.4 (−0.3 to 1.0)	11.8 (−11.4 to 35.1)	0.317

Among members without baseline year cardiovascular comorbid diagnosis, 376 010 were in the HDHP group and 4 005 001 were in the control group. Among members with baseline year cardiovascular comorbidities, 181 493 were in the HDHP group and 1 856 954 were in the control group. AMI, acute myocardial infarction; echo, echocardiogram; ED, emergency department; and HDHP, high-deductible health plan.

*Index ED visits with diagnosis of nonspecific chest pain, as defined in Table I in the Data Supplement.

†Inpatient hospitalization as a result of the ED evaluation (admitted from the index ED visits).

‡Any noninvasive test includes stress ECG, nuclear stress imaging, stress echocardiogram, and coronary computed tomographic angiogram.

where lower socioeconomic status members, after an initial decline in high-severity ED visits after HDHP enrollment, experienced a subsequent uptrend in high-severity ED visits and hospitalizations.[17]

It is important to note that our study was limited to ED visits with a principal ED diagnosis of nonspecific chest pain, excluding ED visits with significant cardiovascular conditions, including AMI. Although we did not evaluate the impact of HDHPs on serious cardiovascular presentations in the overall population, a recent study found no significant changes in AMI admissions and all-cause mortality for up to 4 years after HDHP enrollment.[40] The underlying reason for this discrepancy with our finding is unclear. Although we found a significant association between HDHP enrollment and post-ED AMI admissions among members from higher-poverty neighborhoods, this association did not reach significance in the overall cohort. Furthermore, AMI admissions after an ED diagnosis of nonspecific chest pain represent a small subset of all AMI inpatient episodes. Future studies should validate these findings and elicit the underlying causal mechanism by examining the effects of

HDHP enrollment on ED diagnosis of AMI and other high-acuity conditions, as well as delays in outpatient evaluations for acute cardiovascular symptoms in the general and low-income population.

The contrasting findings between members from neighborhoods of different poverty levels merit particular attention. After HDHP switches, members from lower-poverty neighborhoods reduced invasive procedures after nonspecific chest pain ED visits without changes in ED visits for nonspecific chest pain, hospitalizations, noninvasive testing, or AMI admissions. However, members living in higher-poverty neighborhoods reduced nonspecific chest pain ED visits, disproportionately reduced hospitalizations from index ED visits, and significantly increased AMI hospitalization in 30 days after index ED visits. Our findings support that, although HDHPs can reduce potentially low-value acute care among those with higher socioeconomic status, the disproportionate financial pressure from high out-of-pocket costs on lower-income populations appears to lead to unintended consequences with potentially negative health implications.[17,19] Future research examining HDHPs or other high cost-sharing insurance products should place an

Table 4. ED Visits per 10 000 Person-Years for HDHP and Control Group at Baseline and Follow-Up Years Stratified by Neighborhood Poverty Level

| | Lower-poverty neighborhoods (<10%) | | | | | Higher-poverty neighborhoods (≥10%) | | | | |
| | Baseline | | Absolute change | Relative % change | P value | Baseline | | Absolute change | Relative % change | P value |
	HDHP	Control				HDHP	Control			
Nonspecific chest pain ED visit*	83.3	83.4	−0.4 (−2.3 to 1.4)	−0.4 (−2.4 to 1.5)	0.655	104.1	105.1	−8.7 (−10.0 to −7.4)	−7.3 (−8.3 to −6.3)	<0.001
ED hospitalization†	10.3	10.2	0.06 (−0.5 to 0.7)	0.5 (−4.5 to 5.6)	0.836	12.9	12.9	−2.8 (−3.4 to −2.1)	−15.7 (−19.2 to −12.3)	<0.001
Three-day outcomes										
Any noninvasive test‡	24.3	24.5	−0.6 (2.4 to 1.2)	−2.3 (−8.7 to 4.1)	0.484	27.0	27.2	0.4 (−0.2 to 1.1)	1.4 (−0.7 to 3.5)	0.189
Stress ECG	16.5	16.6	0.5 (−0.8 to 1.8)	2.9 (−4.5 to 10.4)	0.445	19.0	18.4	−0.7 (−1.4 to −0.07)	−3.4 (−6.3 to −0.4)	0.025
Nuclear stress	3.3	3.4	−1.0 (−1.4 to −0.6)	−22.2 (−30.1 to −14.3)	<0.001	4.0	4.5	0.2 (−0.2 to 0.7)	4.1 (−4.8 to 13.0)	0.362
Stress echo	4.3	4.3	−0.1 (−0.6 to 0.4)	−2.2 (−12.2 to 7.9)	0.675	3.8	4.2	1.0 (0.4 to 1.6)	25.7 (7.0 to 44.3)	0.007
Thirty-day outcomes										
Any noninvasive test‡	33.7	34.4	−0.07 (−2.0 to 1.9)	−0.2 (−5.5 to 5.1)	0.947	38.0	38.0	−0.7 (−1.6 to 0.07)	−1.7 (−3.6 to 0.1)	0.07
Invasive angiography	6.6	6.7	−0.6 (−1.0 to −0.1)	−6.9 (−12.3 to −1.5)	0.012	8.7	8.8	−0.5 (−1.1 to 0.2)	−4.3 (−9.9 to 1.4)	0.139
Revascularization	2.0	2.1	−0.5 (−0.9 to −0.07)	−13.2 (−23.4 to −3.1)	0.01	2.7	2.8	0.4 (−0.04 to 0.9)	10.4 (−1.9 to 22.6)	0.097
AMI admission	0.8	0.8	0.1 (−0.3 to 0.5)	6.9 (−20.7 to 34.5)	0.624	0.9	0.9	0.6 (0.3 to 0.9)	29.4 (13.3 to 45.6)	<0.001

There were 290 159 members in the HDHP group and 3 227 091 in the control group from lower-poverty neighborhoods. There were 267 195 in the HDHP group and 2 625 670 in control group from higher-poverty neighborhoods. AMI indicates acute myocardial infarction; echo, echocardiogram; ED, emergency department; and HDHP, high-deductible health plan.

*Chest pain ED visits included ED visits with diagnosis of nonspecific chest pain, as defined in Table I in the Data Supplement.

†Inpatient hospitalization as a result of the ED evaluation (admitted from the index ED visits).

‡Any noninvasive test includes stress ECG, nuclear stress imaging, stress echocardiogram, and coronary computed tomographic angiogram.

additional emphasis on their impact among the low-income population.

Our study has several additional policy and clinical implications. First, our study showed the potential consequences to chest pain care when lower-income populations are exposed to high cost-sharing. There is growing evidence that exposing low socioeconomic status populations to high cost-sharing leads to the deferral of appropriate care,[17,19,41–43] which can explain our finding of higher AMI admissions after index ED visits among members from higher-poverty neighborhoods. Therefore, there is an increasing impetus for employers and insurers to account for income level when determining health benefits, particularly for plan designs with high levels of cost-sharing. Employers offering HDHPs should also consider contributing to health savings accounts[44] to support lower-income employees and those with high baseline medical needs who may not afford the costs of unforeseen medical needs.[45,46]

Second, our findings suggest that HDHPs have limited effects on diagnostic testing decisions during an episode of care despite a wide variation in practice.[8] The underlying reason may be that clinicians have a substantial role in decision-making over diagnostic testing. This view is consistent with previous studies showing the limited impact of increased cost-sharing on within-visit decisions.[37–39] Although also a within-visit decision, patients may have remained sensitive to hospitalizations during ED visits as they entail a more pronounced life interruption and expenditures compared with diagnostic testing. Nevertheless, these findings point to a growing need to incorporate cost-of-care information during shared decision-making between clinicians and patients, at a time when most employees have HDHPs.[14] Recent regulatory changes mandating price transparency are a promising change.[47] With the increasing use of shared decision-making, particularly during ED evaluations for acute chest pain,[48,49] it is also important for future research to examine how clinicians should best integrate cost-of-care information.

Our study incorporated several key design elements to minimize bias. We restricted the cohort to members

Table 5. Hospitalizations From ED Visits With Nonspecific Chest Pain Diagnosis per 10 000 Person-Years for HDHP and Control Group at Baseline and Follow-Up Years

Study year	HDHP (n=557 503)		Control (n=5 861 955)		Absolute change	Relative % change	P value
	Baseline	Follow-up	Baseline	Follow-up			
ED hospitalizations*	12.8	13.1	12.6	14.2	−1.7 (−2.1 to −1.2)	−11.3 (−14.0 to −8.6)	<0.001
During hospital stay:							
Any noninvasive test†	5.7	5.2	5.7	5.6	−0.5 (−1.1 to −0.02)	−9.5 (−18.0 to −1.0)	0.029
Stress ECG	4.2	3.5	3.9‡	3.7	−0.6 (−1.0 to −0.3)	−15.5 (−22.7 to −8.2)	<0.001
Nuclear stress	1.0	1.1	1.1	1.3	−0.08 (−0.3 to 0.1)	−7.3 (−21.9 to 7.4)	0.331
Stress echo	0.5	0.6	0.6	0.5	0.2 (−0.03 to 0.3)	36.8 (−0.3 to 73.8)	0.052
Invasive angiography	4.3	4.4	4.4	4.7	−0.4 (−0.8 to −0.08)	−9.0 (−15.7 to −2.2)	0.009
Revascularization	1.8	2.3	1.9	2.3	0.04 (−0.1 to 0.2)	1.9 (−6.5 to 10.2)	0.662
AMI discharge diagnosis	0.9	1.6	0.9	1.3	0.3 (0.05 to 0.5)	20.5 (1.0 to 40.1)	0.04

AMI indicates acute myocardial infarction; echo, echocardiogram; ED, emergency department; and HDHP, high-deductible health plan.
*Inpatient hospitalization as a result of the ED evaluation (admitted from the index nonspecific chest pain ED visit).
†Any noninvasive test includes stress ECG, stress nuclear imaging, stress echocardiogram, and coronary computed tomographic angiogram.
‡Significant baseline level difference between HDHP and control groups ($P<0.05$).

whose employers mandated deductible levels, reducing selection bias from enrollees who had a choice between HDHPs and lower-deductible plans. In addition to matching each member's baseline year characteristics, we balanced key employer characteristics because employers may self-select into certain insurance types. Last, we matched on baseline outcome levels to reduce potential regression-to-the-mean effects from employer selection into HDHPs because of higher expenditures in the baseline year.

Nevertheless, several limitations should be considered when interpreting these results. First, despite the robust quasi-experimental design, our study remains vulnerable to unmeasured confounders. However, our findings were robust to additional adjustment of potential confounders to cumulative outcomes (Table V in the Data Supplement). Second, the lack of clinical data prevented the determination of ED visit severity. Past studies have shown that switching to HDHPs preferentially reduces low-severity ED visits.[15,16,36,50] Therefore, members likely had higher-acuity chest pain ED visits after HDHP enrollment, in addition to the potential effects of delayed evaluation of concerning cardiac symptoms. Third, we cannot determine if patients admitted after ED diagnosis of nonspecific chest pain, who later received AMI diagnosis at hospital discharge, were misclassified by the ED clinician. However, this potential misclassification would not have impacted HDHP enrollees differently than other members, particularly because payer and cost-sharing information are often not readily available to ED clinicians at the point of care. Fourth, the lack of clinical data also prevented us from determining whether the cardiac testing that occurred adhered to existing practice guidelines. Last, although we have the deductible information of most small employers (<100 employees), we needed to impute the deductibles for nearly all large employers (Methods in the Data Supplement). However,

the imputation method has been validated within the dataset to have high sensitivity and specificity.[18]

Conclusions

Employer-mandated HDHP switches were associated with fewer nonspecific chest pain ED visits and reduced hospitalization from these ED visits, but no significant changes in subsequent cardiac testing after ED diagnosis of nonspecific chest pain. Growing HDHP enrollment will increase patients' need to consider out-of-pocket costs, magnifying the role for future research on how best to integrate cost information into patient-clinician decision-making. We also found HDHP associated with an increase in patients hospitalized after ED diagnosis of nonspecific chest pain who then receive an AMI diagnosis on hospital discharge. This association was disproportionately among lower-income employees. Therefore, employers and insurers should account for income and baseline medical burden when considering cost-sharing for employee coverage.

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