Supplementary Appendix

This appendix has been provided by the authors to give readers additional information about their work.

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Racial Inequality in Prescription Opioid Receipt: Individual Health Systems' Role

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Supplemental Materials

Table of Contents

Data and cohort

We used Medicare data for a random 40% sample of fee-for-service beneficiaries aged 18 to 64 years who were fully enrolled for at least 12 months in inpatient (Part A), outpatient (Part B) and prescription (Part D) plans in 2016, 2017 or both years. We excluded beneficiaries in the calendar year if they turned 65 years old prior to December 31st. We limited our study to enrollees of Black or non-Hispanic White (hereafter White) race, using Research Triangle Institute's race classification in the Medicare Beneficiary Summary file, a variable validated against self-reported race for Black and White race.[1,2] We further limited our study to beneficiaries with a least one primary care service claim in 2016 or 2017, to enable health system attribution. We excluded beneficiaries living outside of the U.S., who qualified for Medicare due to end-stage renal disease, with any hospice use, or with zero Part D prescription drug fills in a year. These exclusions aimed to create a more homogeneous cohort and to minimize the risk of incomplete claims.

Opioid and other prescription fill measures

Using Medicare Part D Prescription Drug Event file data, we constructed four annual measures of prescription opioid receipt at the patient level: any opioid receipt (filled one or more prescriptions in year), short-term receipt (filled an opioid prescription in one, two, or three calendar quarters during the year), long-term receipt (filled one or more opioid prescriptions in all four calendar quarters of a year), and total morphine milligram equivalents (MME) per person-year calculated by converting each prescription fill to an MME value and summing MME by person-year as described in the section below, "Morphine equivalent dose." For a secondary analysis, we measured non-opioid

prescription count, or the number of 30-days' supply for each person-year calculated as the total days' supply received for non-opioids divided by 30.

Table S1. Prescription fill measures at the person-year level

Prescription fill measure	Definition
Any opioid receipt	At least 1 opioid fill in calendar year
Short-term opioid receipt	At least 1 opioid fill in 1, 2, or 3 quarters in calendar year
Long-term opioid receipt	At least 1 opioid fill in all 4 quarters in calendar year
Opioid fill count	Annual number of prescriptions filled for opioid
MME per opioid fill	Annual MME divided by total annual fills with an opioid NDC
Total units (e.g., pills, patches, mL) dispensed per opioid fill	Annual quantity dispensed on opioid fill divided by total annual fills with an opioid NDC
MME per opioid unit (e.g., pills, patches, mL) dispensed	Annual MME divided by the total annual quantity dispensed on opioid fills
Days' supply per opioid fill	Annual days' supply on opioid fills divided by total annual fills with an opioid NDC
Non-opioid prescription 30-day supply count	Total days' supply received for non-opioids divided by 30

Opioid prescription measures presented throughout this paper exclude opioids used in the treatment of opioid use disorder (e.g., buprenorphine). All measures come from the Medicare Part D Prescription Drug Event file. The FirstDataBank database was used to identify opioid products and strength from National Drug Code in the Part D file. MME is morphine milligram equivalents. NDC is National Drug Code.

Morphine equivalent dose

The Medicare Prescription Drug Event includes the National Drug Code (NDC), the date the prescription was filled, the quantity dispensed, and the intended days' supply. The First DataBank database was used to obtain the drug name, dose, and active ingredient for each NDC. To create measures of the intensity of opioid receipt, we converted each opioid product into morphine milligram equivalents (MME), according to opioid conversion factors in Table S2.[3,4]

Table S2: Morphine equivalents conversion table	
Opioid prescription products examined	**Morphine equivalents per milligram**
Codeine	0.15
Hydrocodone	1
Hydromorphone	4
Levorphanol	12
Meperidine	0.1
Methadone	4
Morphine	1
Opium	1
Oxycodone	1.5
Oxymorphone	3
Pentazocine	0.3
Fentanyl	100
Tapentadol	0.37
Tramadol	0.1

Source: Washington State Agency Medical Directors' Group. Opioid Dose Calculator. http://agencymeddirectors.wa.gov/Calculator/DoseCalculator.htm. Published 2015. Accessed May 13, 2020. MedCalc.com. Narcotic Equivalence Converter. http://www.medcalc.com/narcotics.html. Published 2010. Updated Copyright © 1999-2020 MedCalc.com This table identifies opioid conversion factors used in analyses.

Our measure of MME includes methadone. Although methadone is used for addiction management, it is commonly used for pain treatment as well. Methadone used exclusively for opioid addiction management will not appear in retail pharmacy claims, and thus is not reflected in our data, because opioid treatment centers (methadone maintenance clinics) dispense this product directly to patients. Although some observed methadone consumption could reflect unlawful prescribing by clinicians treating opioid addiction outside the setting of an opioid treatment program, we believe the volume of such prescribing is likely to be trivial.

To manage the risk of a small number of extreme prescription fill values (or data errors) skewing our measures, fill-level MME values greater than the 99th percentile were assigned a 99th percentile value.

Covariates and patient characteristics

Table S3 details the definition and file source for each patient characteristic used as a covariate or to define a cohort.

Table S3: Patient characteristic definitions and source

Patient characteristic	Definition	File
Race and ethnicity	Research Triangle Institute definitions	Medicare Beneficiary Summary
Age	As of January 1	Medicare Beneficiary Summary
Sex	Female or male	Medicare Beneficiary Summary
State of residence	As of January 1	Medicare Beneficiary Summary
Long-term-care resident	50% of prescription fills in calendar year from a long-term care pharmacy	Pharmacy Characteristics
Hierarchical Condition Category (HCC) risk score	Version 22 HCC categories from Centers for Medicare and Medicaid services using contemporaneous annual claims	MedPAR, Part B, Outpatient
Cancer diagnosis	See Table S4	MedPAR, Part B, Outpatient

Hierarchical Condition Category (HCC) risk score is a measure of expected medical spending used to calculate payments to Medicare Advantage plans. https://www.cms.gov/Medicare/Health-Plans/MedicareAdvtgSpecRateStats/Risk-Adjustors. Published 2017. Accessed October 16, 2020.

Table S4 provides details on how we identified patients with cancer using the International Classification of Diseases 10th Revision (ICD-10) diagnosis codes that form the basis for Version 22 HCC categories.

Table S4: Codes used for cancer subpopulation identification	
Description	**ICD10 codes or other codes used**
Metastatic cancer and acute leukemia (Hierarchical Condition Category 8)	C77.1-C77.2, C77.4-C77.8, C78.-, C79.00-C79.72, C79.89, C79.9, C7B.-, C80.0, C91.0-, C92.00-C92.02, C92.40-C92.A2, C93.0-, C94.00-C94.22, C94.40-C94.42, C95.0-
Lung and other severe cancers (Hierarchical Condition Category 9)	C15.-, C16.-, C17.-, C22. -, C23, C24.-, C25.-, C33, C34.-, C38.4, C45.-, C48.-, C90.00-C90.22, C92.10-C92.32, C92.Z0-C92.92, C93.10-C93.92, C94.30-C94.32, C94.80-C94.82
Lymphoma and other cancers (Hierarchical Condition Category 10)	C40.-, C41.-, C46.-, C47.-, C49.-, C56.-, C57.00-C57.4, C58, C70.-, C71.-, C72.-, C74.-, C75.1-C75.3, C77.3, C77.9, C79.2, C79.81, C79.82, C81.-, C82.-, C83.-, C84.-, C85.-, C86.-, C88.2-C88.9, C90.3-, C91.-, C95.10-C95.92, C96.-
Colorectal, bladder and other cancers (Hierarchical Condition Category 11)	C01, C02.-, C03.-, C04.-, C05.-, C06.-, C07, C08.-, C09.-, C10.-, C11.-, C12, C13.-, C14.-, C18.-, C19, C20, C21.-, C26.-, C30.-, C31.-, C32.-, C37, C38.0-C38.3, C38.8, C39.-, C51.-, C52, C53.-, C57.7-C57.9, C64.-, C65.-, C66.-, C67.-, C68.-
Breast, prostate and other cancers and tumors (Hierarchical Condition Category 12)	C43.-, C4A.-, C50.-, C54.-, C55, C60.-, C61, C62.-, C63.-, C69.-, C73, C75.0, C75.4-C75.9, C76.-, C7A.-, C80.1, C80.2, D03.-, D18.02, D32.-, D33.-, D35.2-D35.4, D42.-, D43.-, D44.3-D44.7, D49.6, E34.0, Q85.-

Source: US Department of Health & Human Services, Centers for Medicare & Medicaid. HCC Risk Adjustment Model, Version 22. https://www.cms.gov/Medicare/Health-Plans/MedicareAdvtgSpecRateStats/Risk-Adjustors. Published 2017. Accessed October 16, 2020. These categories of conditions are used to calculate a risk score from which expected medical spending is derived. These in turn are used to calculate payments to Medicare Advantage plans.

Patient practice and health system attribution

Our attribution method is analogous to common accountable care organization attribution models.[5] The approach assigns each patient to the single organization (in this case, a health system or practice) delivering the plurality of primary care visits to

that patient in that year. Each National Provider Identifier (NPI) is linked to an organization (health system or for those not in a health system, a practice) in IQVIA's OneKey database.[6,7] Each patient visit was linked to an organization based on the NPI on the claim. Some patients received the plurality of visits from an independent medical practice (e.g., outside any health system). These patients are reflected in descriptions and crude opioid receipt measures for the national sample in Tables 1 and 2, but they are excluded from system-level analyses. Table S5 below shows the distribution of person years across the 310 large, diverse-population systems meeting system inclusion criteria (at least 200 person years each of Black and White race patients in our study period).

Table S5. General cohort characteristics of the 310 systems included in health system-level analyses

	Mean	SD	25th Percentile	Median	75th Percentile	Min	Max
Person-years							
All	2,893	(3,625)	927	1,797	3457.75	433	34,845
Black	750	(785)	279	489	921.75	200	7,236
Non-Hispanic White	2,143	(3,004)	567	1,177	2541.25	212	27,609
Black person-years (% of total)	32.7%	(15.7%)	20.3%	30.7%	44.1%	5.6%	79.5%

We used claims to attribute each patient to an organization in each calendar year based on the plurality of primary care visits. These 310 health systems included in the within-system analysis have at least 200 Black and 200 non-Hispanic White attributed person-years in our study period.

Table S6 below reveals that cohorts of patients included in systems level analyses are similar to cohorts excluded, except for the proportion of each made up of Black patients.

Table S6. Comparison of patient characteristics among 1. Cohorts in health systems included in system-level analyses, 2. Cohorts in health systems excluded from system-level analyses, and 3. All patients attributed to independent practices (excluded from system-level analysis due to lack of a parent health system)

	310 Included Systems		3,376 Excluded Systems		Patients attributed to independent practices*
	System-level mean	SD	System-level mean	SD	Patient-level mean
Age (%)					
18-24	1.5%	(0.6%)	2.0%	(8.1%)	1.2%
25-29	3.3%	(1.0%)	3.7%	(9.7%)	2.7%
30-34	5.2%	(1.2%)	5.6%	(11.1%)	4.6%
35-39	6.9%	(1.3%)	7.1%	(10.9%)	6.6%
40-44	8.6%	(1.3%)	8.7%	(11.8%)	8.3%
45-49	12.1%	(1.2%)	11.7%	(14.0%)	12.0%
50-54	18.2%	(1.5%)	17.3%	(15.8%)	18.3%
55-59	24.0%	(2.1%)	23.7%	(19.1%)	24.7%
60-64	20.2%	(2.9%)	20.2%	(18.3%)	21.6%
Black person-years (%)	32.7%	(15.7%	20.0%	(25.0%	22.7%
Female (%)	53.6%	(4.1%)	51.4%	(23.3%)	52.1%
Long-term care (%)	9.2%	(6.1%)	8.1%	(13.9%)	9.3%
HCC score (SD)	1.16	(0.15)	1.00	(0.56)	1.08 (1.12)

We used the IQVIA OneKey database to link providers on Medicare claims to health systems (integrated delivery systems that own hospitals and practices or medical groups that own practices) and independent (i.e., non-owned) medical practices using National Provider Identifier. We used claims to attribute each patient to an organization in each calendar year based on the plurality of primary care visits. The 310 health systems included in the within-system analysis have at least 200 Black and 200 White attributed person-years in our study period. The excluded organizations were systems with <200 Black and/or <200 non-Hispanic White person-years, systems owned by the US Department of Veterans Affairs or were physician practices with no parent system (i.e., "independent practices"). Values presented for included and excluded systems are means of system-level values. Values presented for independent practices reflect the characteristics of all patients attributed to these practices and not the means across individual independent practices. *Independent practices are physician practices with no parent health system. Patients and person-years attributed to: included systems 615,089 and 896,807; excluded systems 449,723 and 636,872; and independent practices 468,749 and 663,474.

Table S7 below reveals that included systems were larger, more likely to be not-for-profit, and more likely to own hospitals than excluded systems.

Table S7. System characteristics, included and excluded systems				
	Included systems		Excluded systems	
N	310		3,376	
Patients				
Total [a] (N)	669,285		485,880	
Mean per system (SD)	2,159	(2,697)	144	(358)
Person-years				
Total (N)				
Overall	896,807		636,875	
Black	232,587		85,638	
Non-Hispanic White	664,220		551,237	
Mean per system (SD)	2,893	(3,625)	189	(473)
Ownership status (%)				
For profit	12.9%		36.1%	
Not for profit	79.0%		32.8%	
Other (e.g., government)	8.1%		31.2%	
System type (%)				
Integrated delivery system	77.7%		21.4%	
Operates in more than one state (%)	42.9%		14.6%	
No. of practices				
Overall, mean (SD)	109	(197)	10	(22)
Primary care [b] (%)				
None	2.9%		60.8%	
One	3.6%		12.5%	
Multiple	93.6%		26.7%	
No. of hospitals owned				
Count, mean (SD)	9.7	(21)	0.6	(3.3)
None	22.3%		78.6%	
One	9.7%		12.9%	
Multiple	68.1%		8.4%	
Clinical staff, mean (SD)				
Total (physicians and associate providers)	1392	(2209)	87	(481)
Primary care physicians [c]	311	(598)	18	(135)
Specialists [d]	778	(1,285)	46	(235)
Associate providers [e]	303	(434)	22	(121)

This table describes characteristics of health systems (not independent practices) from the IQVIA OneKey database using the most recent year available in our study period (i.e., 2016 or 2017). The 310 included health systems have at least 200 Black and 200 non-Hispanic White attributed person-years in our study period. The excluded systems do not meet these race-specific minimum attributed person years criteria or were owned by the US Department of Veterans Affairs. Means reported are averages of system-level means.

[a] Because patients can be in an included system in one year and an excluded system in another year, the sum of these two totals does not equal number of unique patients in our sample.

[b] *Primary care practice* is defined as a practice with at least three primary care providers.

[c] Doctors of medicine or osteopathic medicine (MD or DO) in family or internal medicine

[d] Non-primary care MDs or DOs

[e] Physician assistants, nurse practitioners or clinical nurse specialists

Statistical analysis

All regression analyses were performed in the sample of patients attributed to 310 large, diverse-population health systems. We estimated the mean Black—White differences in prescription opioid receipt adjusting for patient characteristics, state of residence, and the system where patients received care. To do this, for each outcome, we fit the following linear regression model for years 2016 and 2017:

$$(1)\ E(Y_{ikts}) = \beta_0 + \beta_1 Black_i + \beta_2 System_k + \beta_3 CY16_t + \beta_4 State_s + \beta_3 Covariates_{it}$$

where *Y* is the prescription opioid measure for individual *i* attributed to system *k* in year *t* and residing in state *s*; "System" is a vector of indicators for the system delivering the plurality of primary care visits, "CY16" indicates that an observation was in 2016; "State" is a vector of indicators for a patient's state of residence, and "Covariates" is a vector of patient age, sex, long-term care status, and HCC score as in Table 1. We used a robust sandwich variance estimator, specifying clusters as systems. In these models, since non-Hispanic White patients form the reference race group, the estimate of β_1 yields the adjusted Black—White race difference in Y. Specifically, β_1 indicates whether Black patients received a lower (negative value of β_1) or higher (positive value of β_1) quantity of opioids than White patients, adjusting for patient demographics, clinical conditions, state of residence (many policies regulating controlled substances vary at the state level), and the system to which patients were attributed (Table 3). In these and in all estimates presented in the main text and supplemental materials, 95% confidence intervals around estimated parameters did not adjust for multiplicity, and therefore the resulting inference may not be reproducible.

To obtain system-specific estimates of Black—White race differences in outcomes, we modified the equation above slightly; we dropped the constant term, β_0, standardized each covariate to have a variance-preserving mean of zero (i.e., expressed each covariate as the deviation from its mean), and replaced the Black race term with 310 "Black*System" terms to fit the following linear regression:

$$(2)\ E(Y_{itks}) = \beta_1 Black_i * System_k + \beta_2 System_k + \beta_3 CY16_t + \beta_4 State_s + \beta_5 Covariates_{it}$$

In this specification, the estimated parameters in the vector β_1 represent adjusted system-specific Black—White race differences in Y, estimated parameters in the vector β_2 provide adjusted system-specific means of Y among White patients, and the sum, $\beta_1 + \beta_2$ yields system-specific estimated means of Y among Black patients (Table S10).

For the annual MME among short-term, and separately, long-term opioid recipients, we plotted the adjusted Black value (x-axis) and White value (y-axis) of that measure for each system (Figure 1). Depicted in this way, points that fall along the 45-degree line indicate mean MME receipt was equal comparing Black and White patients.

In secondary analyses, we limited our sample to patients with cancer diagnoses (Table S11) and fit linear regression models like those in main text Table 3 (equation 1 above) to see how Black White opioid receipt differences among those with cancer diagnosis compared to differences observed in the full sample of patients attributed to the 310 systems. In additional secondary analyses, we plotted the adjusted system-specific

Black patient mean value and White patient mean value of each opioid measure according to the fraction Black patients in each of our 310 systems (Figure S1).

Finally, for a more formal decomposition of opioid receipt differences associated with fraction Black in system and individual race differences within systems, we fit linear regression models with a slight modification to equation 1 as shown in equation 3 below.

(3) $E(Y_{ikts}) = \beta_0 + \beta_1 Fraction\ Black\ Race_k + \beta_2(Black_i - Fraction\ Black\ Race_k) + \beta_3 CY16_t + \beta_4 State_s + \beta_3 Covariates_{it}$

In this model, the coefficient on the "Fraction Black Race," expressed as person-years in that system contributed by Black patients (i.e., a fraction between 0 and 1), conveys the difference in each opioid measure, as the fraction Black race in a system increases. A negative estimate of β_1 indicates that patients receive fewer opioids in systems serving more Black patients, as a share of the total, compared to systems serving fewer Black patients. The coefficient itself describes the change related to moving from a system serving only non-Hispanic White patients (Fraction Black Race = 0) to a system that serves only Black patients (Fraction Black Race = 1), while the minimum fraction Black in System is .056 and the maximum is .795. The coefficient β_2 conveys an estimate of the within system Black—White race difference for health systems having a given fraction Black race in system. If observed race differences were driven entirely by the systems to which Black patients are attributed differing from systems to which White

patients are attributed, we would expect β_2 to be zero. Results of these models are in Table S14.

We use estimates from equation (3) to obtain the mean predicted value of each opioid measure for Black patients and, separately, for White patients. These values can be used to decompose the between system and within system race differences in each opioid measure. For example, the mean predicted value of annual MME for a Black patient in system k living in state s at time t (based on estimate in equation 3) would be:

(4) $E\left(MME_{ikts,B}\right) = \widehat{\beta_0} + \widehat{\beta_1} Fraction\ Black\ Race_k + \widehat{\beta_2}(Black\ race_i - Fraction\ Black\ Race_k) + \widehat{\beta_3} CY16_t + \widehat{\beta_4} State_s + \widehat{\beta_5} Covariates_{it}$,

Where the subscript "B" indicates values among Black patients. Averaged across Black patient-years in the model, we could obtain the expected MME value for Black patients:

(5) $E(MME_B) = \widehat{\beta_0} + \widehat{\beta_1}\overline{Fraction\ Black\ Race_B} + \widehat{\beta_2}\left(1 - \overline{Fraction\ Black\ Race_B}\right) + \widehat{\beta_3}\overline{CY16_B} + \widehat{\beta_4}\overline{State_B} + \widehat{\beta_5}\overline{Covariates_B}$,

And for White patients, denoted with the subscript "W", the expected MME would be:

(6) $E(MME_W) = \widehat{\beta_0} + \widehat{\beta_1}\overline{Fraction\ Black\ Race_W} + \widehat{\beta_2}\left(0 - \overline{Fraction\ Black\ Race_W}\right) + \widehat{\beta_3}\overline{CY16_W} + \widehat{\beta_4}\overline{State_W} + \widehat{\beta_5}\overline{Covariates_W}$.

Focusing just on the between system estimates (Fraction Black race) and within system estimates (Black race – Fraction Black) and ignoring the contribution to race differences of patient characteristics or calendar year, we can subtract the first three terms in equation (6) from those terms in equation (5) and thus decompose the expected Black—White difference in MME due to between system and within system race differences (holding constant patient characteristics) as:

between system race difference

$$(7)\ E(MME_B - MME_W) = \widehat{\beta_1}\left(\overline{Fraction\ Black\ Race_B} - \overline{Fraction\ Black\ Race_W}\right) + \widehat{\beta_2}\left(\overline{1 + Fraction\ Black\ Race_W} - \overline{Fraction\ Black\ Race_B}\right).$$

within system race difference

Black—White differences in prescription opioid measures

Table S8 provides full output of linear regression models summarized in Table 3 of the manuscript.

Table S8. Complete regression results for main text Table 3

Table S8a: Any opioid receipt (one or more prescription fill in calendar year)

Covariate	Estimate	Lower CI	Upper CI
Black race (vs white)	-3.3%	-4.0%	-2.6%
Female sex (vs male)	9.4%	9.1%	9.7%
Age			
18-24	-22.2%	-23.0%	-21.0%
25-29	-14.8%	-16.0%	-14.0%
30-34	-9.9%	-11.0%	-9.2%
35-39	-5.4%	-6.1%	-4.7%
40-44	-1.8%	-2.4%	-1.3%
45-49	0.2%	-0.3%	0.6%
50-54	2.8%	2.4%	3.2%
55-59	2.4%	2.0%	2.7%
60-64 (ref)	ref	ref	ref
HCC score	8.1%	7.9%	8.2%
Long-term care	-28.9%	-30.0%	-28.0%
Year (=2016)	3.3%	3.0%	3.6%

Percent with any opioid receipt =51.7%
Model R^2 =0.115

Table S8b. Short-term opioid receipt (prescription fill in 1 to 3 calendar quarters in the year)			
Covariate	**Estimate**	**Lower CI**	**Upper CI**
Black race (vs white)	1.7%	1.3%	2.0%
Female sex (vs male)	4.0%	3.8%	4.3%
Age			
18-24	-2.5%	-3.3%	-1.7%
25-29	1.4%	0.8%	2.0%
30-34	2.5%	2.0%	3.1%
35-39	2.6%	2.1%	3.1%
40-44	1.8%	1.4%	2.3%
45-49	1.2%	0.8%	1.6%
50-54	0.7%	0.3%	1.0%
55-59	0.1%	-0.1%	0.4%
60-64 (ref)	ref	ref	ref
HCC score	3.4%	3.2%	3.5%
Long-term care	-10.9%	-11.0%	-10.0%
Year (=2016)	1.2%	1.0%	1.4%

Percent with short-term opioid receipt = 26.5%
Model R^2 = 0.021

Table S8c: Long-term opioid receipt (prescription fill in all 4 calendar quarters in the year)			
Covariate	**Estimate**	**Lower CI**	**Upper CI**
Black race (vs white)	-5.0%	-5.7%	-4.2%
Female sex (vs male)	5.4%	5.1%	5.7%
Age			
18-24	-19.7%	-21.0%	-19.0%
25-29	-16.2%	-17.0%	-15.0%
30-34	-12.4%	-13.0%	-12.0%
35-39	-8.0%	-8.6%	-7.4%
40-44	-3.7%	-4.2%	-3.2%
45-49	-1.1%	-1.5%	-0.6%
50-54	2.1%	1.7%	2.6%
55-59	2.2%	1.9%	2.6%
60-64 (ref)	ref	ref	ref
HCC score	4.7%	4.6%	4.8%
Long-term care	-18.0%	-19.0%	-17.0%
Year (=2016)	2.0%	1.7%	2.4%

Percent with long-term opioid receipt = 25.2%
Model R^2 = 0.081

Table S8d: Total MME overall (non-recipients included)			
Covariate	**Estimate**	**Lower CI**	**Upper CI**
Black race (vs white)	-3,140	-3465.2	-2815.3
Female sex (vs male)	258	115.9	400.5
Age			
18-24	-4,410	-4726.3	-4093.8
25-29	-3,208	-3545.6	-2870.4
30-34	-2,181	-2477.4	-1884.7
35-39	-660	-948.3	-372.2
40-44	840	593.5	1086.5
45-49	1,380	1138.8	1620.5
50-54	2,007	1799.9	2214.8
55-59	1,520	1352.4	1688.1
60-64 (ref)	ref	ref	ref
HCC score	1,968	1866.6	2069.2
Long-term care	-6,599	-6902.1	-6295.6
Year (=2016)	1,131	989.2	1272.2

Annual MME mean, all person-years = 7,332
Model R^2 = 0.038

Table S8e: Total MME among short-term opioid recipients			
Covariate	**Estimate**	**Lower CI**	**Upper CI**
Black race (vs white)	-588	-656.4	-519.7
Female sex (vs male)	-246	-291.8	-199.5
Age			
18-24	-780	-874.1	-685.0
25-29	-511	-615.4	-406.2
30-34	-314	-415.8	-213.2
35-39	32	-60.3	125.0
40-44	190	94.8	286.1
45-49	324	234.7	413.4
50-54	324	240.8	406.3
55-59	200	134.5	265.3
60-64 (ref)	ref	ref	ref
HCC score	358	326.6	388.7
Long-term care	-687	-783.6	-590.8
Year (=2016)	142	96.2	187.4

Annual MME mean, short-term recipients = 1,670
Model R^2 = 0.020

Table S8f: Total MME among long-term opioid recipients			
Covariate	**Estimate**	**Lower CI**	**Upper CI**
Black race (vs white)	-7,232	-7938.2	-6525.3
Female sex (vs male)	-4,926	-5342.8	-4509.3
Age			
18-24	368	-4018.1	4754.8
25-29	4,753	2225.8	7279.2
30-34	4,035	2511.3	5557.8
35-39	5,472	4369.9	6574.3
40-44	6,453	5680.5	7226.5
45-49	5,508	4811.1	6205.3
50-54	4,551	4043.3	5059.7
55-59	2,964	2489.7	3437.7
60-64 (ref)	ref	ref	ref
HCC score	1,603	1402.6	1804.2
Long-term care	-10,927	-11854.5	-10000.3
Year (=2016)	1,999	1700.4	2296.9
Annual MME mean, long-term opioid recipients = 27,368			
Model R^2 = 0.049			

Values in these tables are derived from linear regression models. The unit of analysis is person-year. The sub-population in these models includes 896,807 person-years (615,089 unique patients) attributed to 310 health systems with at least 200 Black and 200 non-Hispanic White attributed person-years in our study period. Models include the following person-year-specific patient characteristics: age category, sex, Hierarchical Condition Category (HCC) score, long-term care residence status (50% or more prescription fills dispensed by a long-term care pharmacy), year, the patient's state of residence, and the health system at which the patient received the plurality of primary care services in the year. Estimated standard errors used sandwich variance estimators specifying system level clusters. CI is confidence interval. CI is not adjusted for multiple comparisons. MME is morphine milligram equivalents.

Next, we show the mean and distribution of each adjusted, system-specific opioid measure in 310 diverse-population health systems used in our regression analyses.

Table S9: Distribution of adjusted health system-level race differences in opioid measures, among 310 large, diverse-population health systems

Annual measures	Mean	Median	25th percentile	75th percentile	Interquartile range
Any opioid receipt (%)					
Black - White difference	-3.4%	-3.7%	-6.5%	-0.5%	6.0%
Black/White ratio	0.94	0.93	0.88	0.99	0.11
Short-term opioid receipt (%)					
Black - White difference	1.4%	1.3%	-0.7%	3.5%	4.2%
Black/White ratio	1.06	1.05	0.97	1.14	0.17
Long-term opioid receipt (%)					
Black - White difference	-4.8%	-4.7%	-8.3%	-0.9%	7.4%
Black/White ratio	0.83	0.81	0.68	0.96	0.29
Mean annual MME overall (including non-recipients)					
Black - White difference	-3,037	-3,065	-4,185	-1,387	2,798
Black/White ratio	0.65	0.60	0.44	0.79	0.35
Mean annual MME among short-term recipients					
Black - White difference	-588	-535	-869	-231	638
Black/White ratio	0.72	0.68	0.54	0.83	0.29
Mean annual MME among long-term recipients					
Black - White difference	-7,214	-7,766	-11,119	-3,799	7,320
Black/White ratio	0.76	0.72	0.63	0.86	0.23

Table displays summary statistics of adjusted system-level differences in prescription opioid receipt measures by race. Health systems included in this summary table are the 310 systems that have at least 200 Black and 200 Non-Hispanic White patient attributed person-years in our study period. Overall, these 310 systems care for 615,089 unique patients (896,807 person-years). MME is morphine milligram equivalents. MME values are top coded (at the fill level) to the 99th percentile of MME.

Supplemental Table S10 – system specific estimates (available online in an Excel spreadsheet in Supplementary Appendix 2).

Secondary analyses: Black—White difference in opioid measures, patients with cancer diagnosis

Below we show results of estimating equation 1 in a sample of patients with cancer

diagnoses.

Table S11. Adjusted Black—White race difference in prescription opioid measures among patients with cancer diagnosis				
	Black race estimate	**Lower CI**	**Upper CI**	**R^2**
Prescription opioid receipt (%)				
Any (at least one prescription fill)	1.8%	-0.6%	4.2%	0.138
Short-term (prescription fill in 1-3 calendar quarters)	2.7%	0.5%	4.8%	0.052
Long-term (prescription fill in 4 calendar quarters)	-0.8%	-3.7%	2.0%	0.113
Annual morphine milligram equivalents				
Overall (non-recipients included)	-4,217	-6,277	-2,158	0.092
Among short-term recipients	-737	-1,296	-177	0.135
Among long-term recipients	-10,394	-15,446	-5,342	0.158

Each estimate represents the effect of being Black (vs non-Hispanic White) in linear regression models. The unit of analysis is person-year. These secondary analyses are restricted to 5,893 unique patients (11,786 patient-years) who had a cancer diagnosis in both years, from the sub-population attributed to the 310 large, diverse health systems. The presence of cancer was determined based on appearance of one or more claim with any diagnosis included in the Hierarchical Condition Categories (HCC) for cancer: HCC8 (Metastatic Cancer and Acute Leukemia), HCC9 (Lung and Other Severe Cancers), HCC10 (Lymphoma and Other Cancers), HCC11 (Colorectal, Bladder, and Other Cancers) or HCC12 (Breast, Prostate, and Other Cancers and Tumors). The model includes the following person-year-specific patient characteristics: age, sex, HCC score, long-term care residence (50% or more prescription fills dispensed by a long-term care pharmacy), state of residence, the health system at which the patient received the plurality of primary care services in the year, and year. Standard errors are based on a robust sandwich variance estimator, specifying clusters as systems. CI is confidence interval. CI does not adjust for multiple comparisons.

Secondary analyses: Black—White difference in opioid measures adjusted for non-opioid prescription volume

Below we present results of estimating equation 1 including a control for total annual prescription 30-day supplies for drugs other than opioids.

Table S12. Adjusted Black—White race difference in prescription opioid measures, accounting for count of non-opioid 30-day prescriptions received				
	Black race estimate	**Lower CI**	**Upper CI**	**R^2**
Prescription opioid receipt (%)				
Any (at least one prescription fill)	-1.9%	-2.5%	-1.2%	0.128
Short-term (prescription fill in 1-3 calendar quarters)	1.3%	1.0%	1.7%	0.022
Long-term (prescription fill in all 4 calendar quarters)	-3.2%	-3.9%	-2.5%	0.107
Annual morphine milligram equivalents				
Overall (non-recipients included)	-2,741	-3,057	-2,424	0.043
Among short-term recipients	-605	-675	-536	0.020
Among long-term recipients	-7,386	-8,086	-6,685	0.049

Each estimate represents the effect of being Black (vs non-Hispanic White) in a linear regression model. The unit of analysis is person-year. These secondary analyses are restricted to 896,807 person-years (615,089 unique patients) attributed to 310 large, diverse health systems. The model includes the following person-year-specific patient characteristics: age, sex, Hierarchical Condition Category (HCC) score, long-term care residence (50% or more prescription fills dispensed by a long-term care pharmacy), indicators for state of residence and for the health system at which the patient received the plurality of primary care services in the year, indicator for year (2016) and annual number of 30-day supplies of non-opioid prescriptions. The mean 30-day non-opioid volume of 30-day supplies (crude) for non-Hispanic White patients is 62.9 (standard deviation=45.9) and for Black patients is 52.3 (standard deviation=42.5). Standard errors are based on a robust sandwich variance estimator, specifying clusters as systems. CI is confidence interval. CI not adjusted for multiple comparisons.

Secondary analyses: Distribution of opioid fill characteristics

The table below displays the distribution of opioid fill count and fill characteristics: MME and units dispensed, MME per opioid unit (product strength), and days' supply per opioid per fill.

Table S13. Distribution of crude opioid prescription fill count and fill characteristics, by race and opioid receipt pattern						
	All patients		Short-term recipients		Long-term recipients	
	Black	White	Black	White	Black	White
Opioid fill count						
5th percentile	0.0	0.0	1.0	1.0	6.0	7.0
25th percentile	0.0	0.0	1.0	1.0	11.0	12.0
Median	1.0	1.0	2.0	2.0	13.0	13.0
Mean	4.0	5.0	2.8	3.1	14.6	15.9
75th percentile	5.0	9.0	3.0	4.0	16.0	21.0
95th percentile	17.0	24.0	8.0	9.0	27.0	29.0
MME per opioid fill						
5th percentile	60.0	70.0	54.0	54.0	218.2	243.1
25th percentile	150.0	180.0	100.0	100.0	491.7	600.0
Median	350.7	482.3	168.8	191.3	900.0	1,093.2
Mean	728.3	961.1	301.9	374.8	1,284.3	1,536.4
75th percentile	900.0	1,200.0	315.0	400.0	1,537.5	1,836.0
95th percentile	2,700.0	3,600.0	900.0	1,279.9	4,050.0	4,696.9
Total units dispensed per opioid prescription fill						
5th percentile	12.0	12.0	10.0	10.0	30.0	30.5
25th percentile	25.0	30.0	18.0	20.0	60.0	62.5
Median	54.2	60.0	30.0	30.0	85.2	90.0
Mean	60.9	70.3	40.5	44.5	87.5	95.6
75th percentile	90.0	96.7	54.0	60.0	109.3	120.0
95th percentile	129.2	162.9	100.0	120.0	157.7	180.0
MME per opioid unit dispensed (strength of product)						
5th percentile	4.5	4.8	4.5	4.5	5.0	5.0
25th percentile	5.0	5.0	5.0	5.0	7.5	7.5
Median	7.5	7.5	5.0	5.6	10.0	10.0
Mean	10.8	13.7	7.1	8.0	15.7	19.2
75th percentile	10.0	12.8	7.5	7.5	15.0	20.1
95th percentile	30.0	40.1	13.1	15.0	45.0	52.5
Days' supply per opioid prescription fill						
5th percentile	2.4	2.7	2.0	2.0	9.7	11.0
25th percentile	5.0	6.7	4.0	4.0	22.0	24.1
Median	17.0	22.0	6.8	7.0	27.6	28.2
Mean	17.0	18.9	10.9	11.5	25.0	26.1
75th percentile	28.2	29.6	15.6	16.8	30.0	30.0
95th percentile	30.0	30.0	30.0	30.0	30.0	30.0

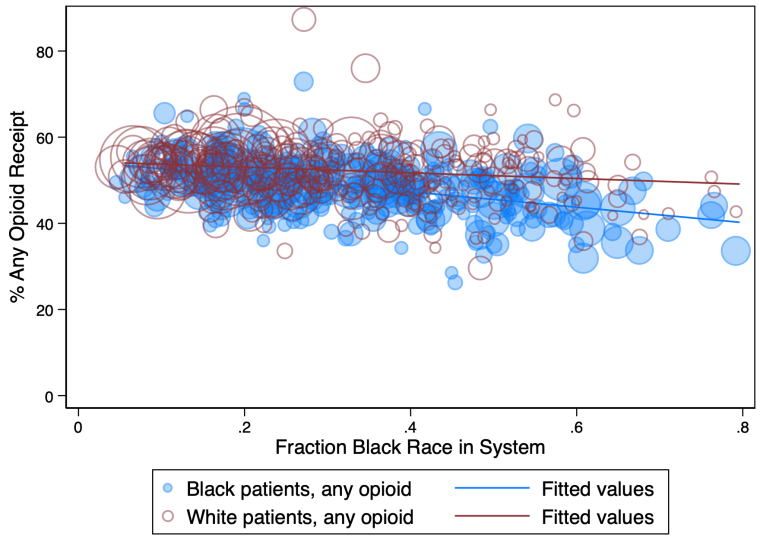
Table displays summary statistics of opioid prescriptions among individual Black and White patients attributed to 310 health systems included in system-level analyses. These systems have at least 200 Black and 200 White patient attributed person-years in our study period. Overall, these 310 systems care for 615,089 patients (896,807 person-years). MME is morphine milligram equivalents. MME values are top coded (at the fill level) to the 99th percentile of MME.

Secondary analyses: Fraction Black patients in system

To explore health systems' estimated Black—White differences varied with racial composition, for each of the 310 large, diverse-population systems, we graphed the value of each prescription opioid measure for Black and White patients by the system's fraction Black patients (Figures S1a-f). We included race-specific lines of best fit and the associated coefficients (slopes) and 95% confidence intervals, without adjusting for multiplicity. Each system's plotted point, and the overall fitted line, are weighted by patient years. The graphs reveal interesting patterns. For most (4 of 6) measures, system-level fraction Black patients is inversely related to opioid receipt measure values for Black patients; the fitted lines have a negative slope. This is not the case for White patients whose opioid receipt is generally unaffected by fraction Black patients in the system; an exception to this pattern is MME among long-term opioid recipients. Among White patients, MME is higher in systems with a higher fraction of Black patients (S1f).

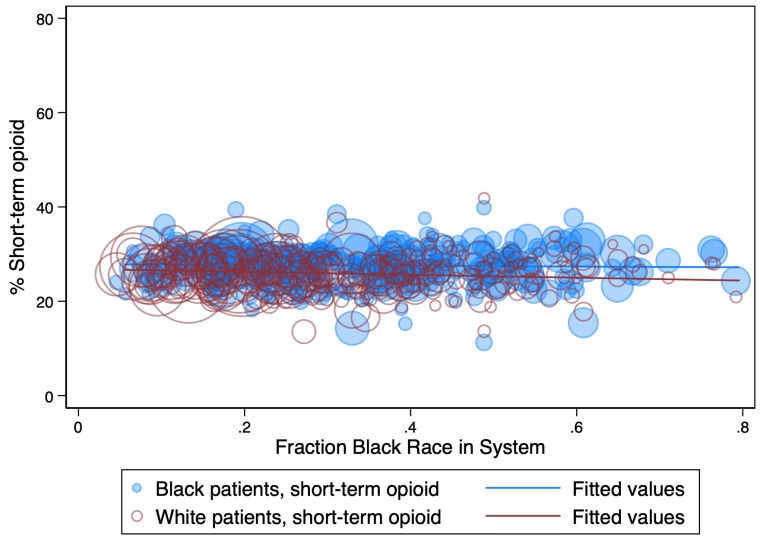
Figure S1. System and Race-Specific Prescription Opioid Measures by Fraction Black Race in System

S1a. Any opioid receipt, %



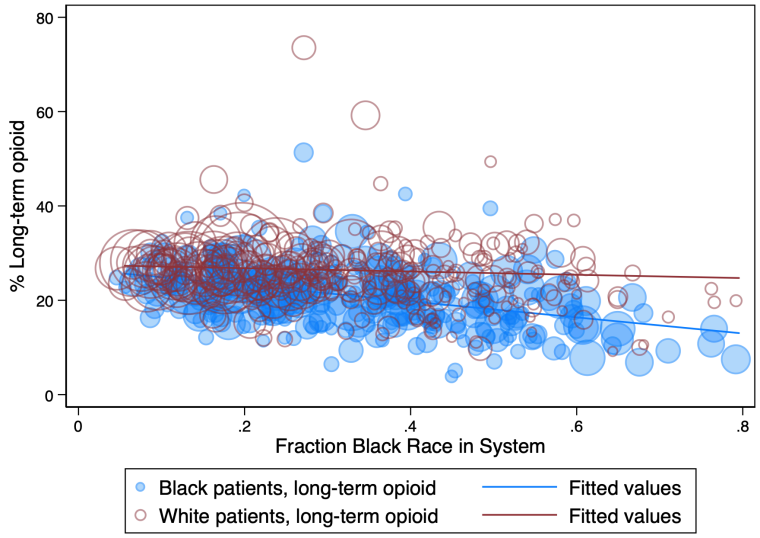
slope (95% CI) = -17.9 (-21.3 to -14.4) for Black patients R^2 = 0.250
slope (95% CI) = -6.6 (-10.5 to -2.7) for White patients R^2 = 0.034

S1b. Short-term opioid receipt, %



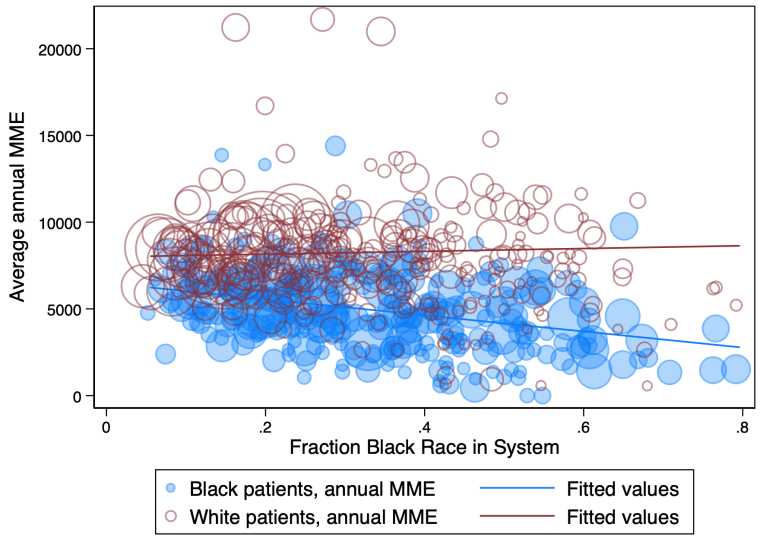
slope (95% CI) = -0.84 (-3.11 to 1.43) for Black patients R^2 = 0.002
slope (95% CI) = -3.1 (-4.94 to -1.26) for White patients R^2 < 0.034

S1c. Long-term opioid receipt, %



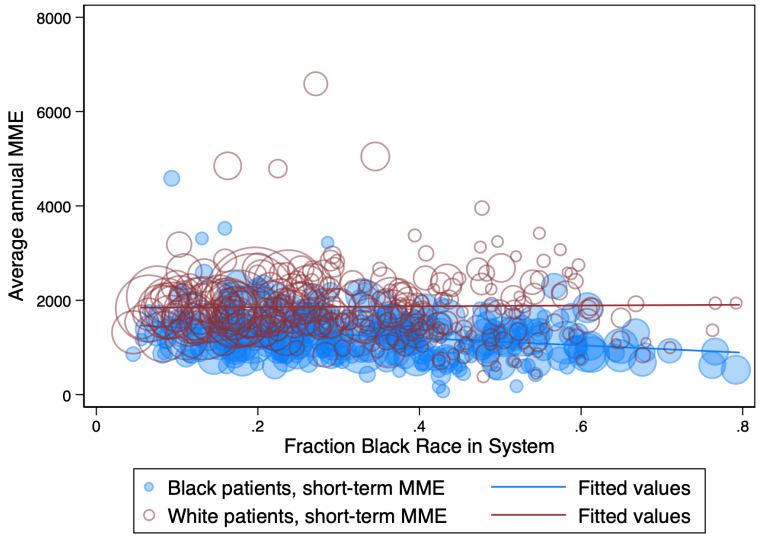
slope (95% CI) = -17.0 (-20.6 to -13.5) for Black patients R^2 = 0.227
slope (95% CI) = -3.5 (-7.8 to .75) for White patients R^2 = 0.008

S1d. Annual MME, overall (non-recipients included)



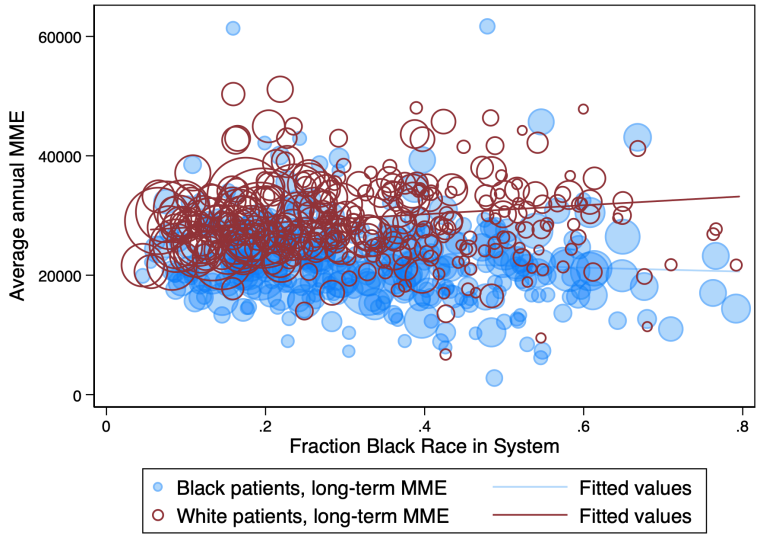
slope (95% CI) = -4,655 (-5,969 to -3,341) for Black patients R^2 = 0.137
slope (95% CI) = 811 (-977 to 2,600) for White patients R^2 = 0.003

S1e. Annual MME, short-term opioid recipients



slope (95% CI) = -773 (-1,049 to -497) for Black patients, R^2 = 0.090
slope (95% CI) = 82 (-356 to 520) for White patients, R^2 = 0.0004

S1f. Annual MME, long-term opioid recipients



slope (95% CI) = -3,305 (-7,521 to 911) for Black patients R^2 = 0.008
slope (95% CI) = 7,493 (3,306 to 11,680) for White patients R^2 =0.039

Figure S1 Note: Fitted lines are weighted by race-specific patient-years in each system. Each dot represents one of the 310 systems studied. The size of the dot reflects relative size of the race-specific cohort size. MME = morphine milligram equivalent.

Table S14 shows a more formal model-based estimate obtained by estimating equation

3. In Table S14, the coefficient on “Fraction Black race” displays an estimated slope of

the line showing the mean change in opioid measure as fraction Black race in a system increases from 0 to 1. Beneath the coefficient estimate, in brackets, we show the estimated Black—White race difference arising from *between system differences* (the effect of Black patients, on average, sorting to lower opioid prescribing systems). The coefficient on “Black race - fraction Black race” displays an estimate of the mean Black—White difference holding constant the fraction Black race in system; beneath it we display the estimated Black—White race difference arising from *within system race differences*. In every case, the within system Black—White gap in opioid receipt is substantially larger (in magnitude) than the between system race difference. We conclude that the large difference in total opioids received among Black versus White patients stems from race differences in opioid receipt within health systems, and not from differences in which systems serve Black patients versus White patients.

Table S14. Estimated change in opioid measures associated with change in fraction Black patients in system vs. individual Black race

	Fraction Black in system			Black race - fraction Black in system			
	Coefficient [Between-system difference]	Lower CI	Upper CI	Coefficient [Within-system difference]	Lower CI	Upper CI	R^2
Prescription opioid receipt (%)							
Any (at least one prescription fill)	-17.9 [-1.9]	-22.0	-14.0	-3.5 [-3.1]	-4.2	-2.8	0.109
Short-term (fill 1-3 calendar quarters)	-1.3 [-0.1]	-3.1	0.6	1.6 [1.5]	1.3	0.2	0.019
Long-term (fill in 4 calendar quarters)	-16.7 [-1.8]	-20.0	-13.0	-5.1 [-4.6]	-5.9	-4.4	0.072
Total MME							
Overall (non-recipients included)	-4,945 [-537]	-6,495	-3,396	-3,161 [-2,817]	-3,484	-2,838	0.032
Among short-term recipients	-997 [-108]	-1,263	-731	-585 [-521]	-651	-518	0.016
Among long-term recipients	-2,033 [-221]	-6,296	-2,230	-7,146 [-6,369]	-7,867	-6,425	0.038
Mean fraction Black race among patient-years attributed to 310 diverse-population systems = 0.259							

Values in this table are derived from an ordinary least-squares regression model. The unit of analysis is person-year. The sub-population in the model includes 896,807 person-years (615,089 unique patients) attributed to 310 health systems with at least 200 Black and 200 non-Hispanic White attributed person-years in our study period. Estimates shown represent the percentage point change in opioid receipt or the change in annual MME as fraction Black race in a health system changes from 0 to 1. The model includes person-year-specific patient characteristics (age category, sex, Hierarchical Condition Category (HCC) score, long-term care residence status (50% or more prescription fills dispensed by a long-term care pharmacy), year and the patient's state of residence. Estimated standard errors were adjusted for correlation within health system using sandwich estimators. CI is confidence interval. CI is not adjusted for multiple comparisons. Between system difference is calculated as β_1*(Black mean – White mean of "fraction Black race in system"). Within system difference is calculated as β_2*(Black mean – White mean of "Black race – fraction Black race in system"). MME = morphine milligram equivalent.

Comparison of Black and White decedents

Our sample frame excluded individuals who died during the calendar year, which could differentially affect Black and White patients if racial death rates differ meaningfully. To examine this, we studied death among patients attributed to our 310 systems in 2016 (i.e., alive on December 31, 2016). We computed crude death rates in 2017 for Black and White patients. Death occurred in 2.51% of White patients and 2.22% of Black patients, meaning that we differentially excluded more White than Black patients. To understand how the higher death rates among White patients might influence estimated Black—White opioid receipt differences, we measured race differences in MME among those dying in the first quarter (Q1) of 2017 and those surviving the full 2017 year. We framed this as a coarse measure of the relationship between proximity of death and opioid dose. Table S15 displays the morphine equivalents in 2016 for those dying in Q1 of 2017 and those surviving through December 31, 2017. Among Q1 2017 decedents, White patients received substantially more MME than Black patients in 2016; the biggest difference was seen among long-term opioid recipients. (In this case, at least one opioid fill all four quarters in 2016.) From this we conclude that, if anything, our analysis may understate the extent to which White patients receive more opioids than Black patients, because we exclude a population (near death) with even greater racial opioid dose differences.

Table S15. Crude 2016 MME by 2017 survival status and race, among patients attributed to 310 diverse systems, alive on December 31, 2016 (N=451,041 patients)						
	Died in Q1 of 2017			Survived 2017		
	Black	White	B-W difference	Black	White	B-W difference
Patients alive on 12/31/2016 (%)	0.55%	0.62%	-0.07%	97.78%	97.48%	0.30%
2016 MME, mean ± SD						
Overall, includes non-recipients	8,774±24,423	13,950±31,539	-5,176	5,392±18,300	8,578±24,585	-3,186
Among short-term recipients	1689±3351	3,146±7,336	-1,457	1,260±3,889	1,863±6,137	-603
Among long-term recipients	27,470±38,879	35,135±43,944	-7,665	22,624±33,243	29,717±39,599	-7,093

Note: The 2017 death rate for patients alive on December 31, 2016: Overall 2.44%: 2.22% among Black patients, 2.51% among White patients. The table above excludes Q2-Q4 2017 decedents. This calculation excluded 187 (75 (0.06%) Black, 112 (0.03%) White) patients who did not appear in the 2017 Master Beneficiary Summary File. MME = morphine milligram equivalents. Q1 = first three months of the calendar year.

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