Impact of Social Factors on Racial Differences in Cardiac Rehabilitation Participation

by

Emily Nicole Guhl

BA, Washington University in St. Louis, 2010

MD, University of Chicago – Pritzker School of Medicine, 2014

Submitted to the Graduate Faculty of theDepartment of Epidemiology

Graduate School of Public Health partial fulfillment

of the requirements for the degree of

Masters of Epidemiology

University of Pittsburgh

2021

UNIVERSITY OF PITTSBURGH

GRADUATE SCHOOL OF PUBLIC HEALTH

This thesis was presented

by

Emily Nicole Guhl

It was defended on April 9, 2021

and approved by

Committee Member: Akira Sekikawa, MD MPH PhD, Associate Professor, Department of Epidemiology, Graduate School of Public Health, University of Pittsburgh

Committee Member/Academic Advisor: Emma Barinas-Mitchell PhD, Associate Professor, Department of Epidemiology, Graduate School of Public Health, University of Pittsburgh

Thesis Advisor or Dissertation Director: Jared W. Magnani, MD MSc, Associate Professor, Department of Cardiology, University of Pittsburgh

Impact of Social Factors on Racial Differences in Cardiac Rehabilitation Participation

Emily Nicole Guhl, MS

University of Pittsburgh, 2021

Abstract

Background: Cardiac rehabilitation (CR) is a multidisciplinary program that employs structured exercise training for secondary prevention of cardiovascular disease. CR improves mortality, rehospitalizations, patient-centered outcomes, and recurrent cardiovascular events. CR participation rates are suboptimal with disparities among nonwhite minorities. We sought to determine the participation rate among CR-eligible patients stratified by race and to evaluate the social factors associated with racial differences in participation.

Methods: Using administrative claims data, we identified adults with CR-eligible diagnoses between 2016-2018. Sociodemographic and clinical factors including age, race, sex, Elixhauser Comorbidity Index, hypertension, diabetes, ischemic stroke, household income, household net worth, education level, and qualifying diagnosis type were obtained for each individual. We determined rate of CR participation using billing codes and stratified by race. Odds of enrolling in CR by clinical and sociodemographic characteristics was obtained using multivariable logistic regression with interaction terms for social factors (educational level, household income) and race.

Results: Our final analytic sample included 124,963 CR-eligible individuals who wereon average 70 years old, 62.3% male, 75.1% white race, 11.7% with a Bachelor's Degree or higher, 31.5% with a household income <40K, 92.6% with hypertension, and 50.4% with diabetes. There was a 25.7% participation rate in CR. Compared to White individuals, Black,

Hispanic, and Asian individuals were 25%, 52%, and 45% less likely to participate in CR, ($p<0.0001$). Individuals with female sex, non-procedural qualifying diagnosis, lower education level, lower income, and comorbidities were less likely to participate in CR, (all, $p<0.0001$). We found significant interactions between race and education ($p=0.0059$) and race and household income ($p=0.0158$) on CR-participation.

Public Health Significance: The confirmation of the suboptimal cardiac rehabilitation participation rate indicates room for improvement to increase cardiac rehabilaition participation use overall. While it is established that race is a predictor of CR participation, our study adds to the body of evidence by identifying social factors, such as income and education, as both independent predictors and moderator of participation. Additionally, understanding the dynamics of enrollment, initiation, and adherence by race informs where the gaps in the pathway are occurring, to address disparities and improve outcomes in vulnerable populations.

Table of Contents

List of Tables

List of Figures

1.0 Background

1.1 Introduction to Cardiac Rehabilitation and Indications

Cardiac rehabilitation is a multidisciplinary program that combines structured exercise training with nutritional counseling, risk factor modification (smoking, lipids, hypertension, diabetes, weight), patient education, and psychosocial counseling.[1] The goal of cardiac rehabilitation is secondary prevention to stabilize, slow, or reverse the progression of cardiovascular disease.[1] Current American College of Cardiology/American Heart Association guideline recommendations give cardiac rehabilitation a class 1 recommendation for individuals with recent myocardial infarction or acute coronary syndrome, chronic stable angina, coronary artery bypass grafting, percutaneous coronary intervention, heart transplant, valve surgery, or peripheral arterial disease.[2] Cardiac rehabilitation is a class II indication for stable systolic heart failure.[3] With these diagnoses, conservative models estimate over 2 million cardiac rehabilitation qualifying events in the United States per year, representing 1.1 million individuals.[4] Cardiac rehabilitation is recommended to be initiated immediately after the qualifying cardiovascular event, ideally prior to hospital discharge in hospitalized patients. It consists of an outpatient program traditionally composed of 36 in-person sessions including a structured exercise followed by a maintenance phase focused on independence and self-monitoring.

1.2 Effectiveness of Cardiac Rehabilitation

Given the primary goal of cardiac rehabilitation is secondary prevention, the effectiveness of the program on mortality, rehospitalizations, recurrent cardiovascular events,patient centered outcomes, and exercise measures/functional capacity has been studied in a number of trials with promising results.

1.2.1 Mortality

Multiple studies have demonstrated significant reductions in mortality associated with cardiac rehabilitation. In a large cohort of over 600,000 US Medicare beneficiaries who were hospitalized for coronary conditions or revascularizations, those who utilized cardiac rehabilitation had 5-year mortality rates that were 21-35% lower than those who did not.[5] Similarreductions were seen in a Dutch cohort of over 83,000 individuals with cardiac rehabilitation- eligible conditions; cardiac rehabilitation participation was associated with a 32% lower risk of mortality over a 7.5 year follow-up period compared to nonparticipation.[6] In a valvular surgery and coronary artery bypass grafting population of 201 patients in Olmsted County, participation in CR was associated with an absolute risk reduction of mortality of 14.5% over 10 years.[7] To further strengthen the evidence, a dose-dependent effect of cardiac rehabilitation on mortality has also been demonstrated. In a national 5% sample of Medicare beneficiaries, when compared to those who completed at least 24 sessions, at least 12 sessions, or only 1 session, those who completed all 36 sessions had 14%, 22% and 47% lower risk of mortality, respectively.[8]

1.2.2 Rehospitalizations

In a prospective cohort of 5886 subjects undergoing angiography and referred for cardiac rehabilitation, completion of cardiac rehabilitation was associated with decreased all-cause (HR 0.77) and cardiac (HR 0.68) hospitalizations.[9] Another cohort of nearly 3000 patients in Olmsted County discharged with first myocardial infarction also found that those who participated in cardiac rehabilitation had lower all-cause (HR 0.75) and cardiovascular readmission (HR 0.80) when compared to non-participation.[10]

1.2.3 Recurrent Cardiovascular Events

Reinfarction rates were studied in individuals post-myocardial infarction, in a meta-analysis of 34 trials including 6111 subjects, exercise-based cardiac rehabilitation was associated with a significantly lower reinfarction rate (OR 0.53).[11] To add to this evidence there was a dose-dependent effect of cardiac rehabilitation for preventing myocardial infarction with those completing 36 sessions having a 12% lower risk of myocardial infarction compared to those completing 24 sessions and a 31% lower risk of myocardial infarction compared with 1 session.[8]

1.2.4 Patient-Centered Outcomes

In addition to decreased rates of mortality and cardiovascular events, cardiac rehabilitation has been associated with improved patient-centered outcomes including quality of life and depression levels. In a study of 139 patients undergoing cardiac rehabilitation in Singapore, participants were administered questionnaires before and after completion and foundto have higher levels of both physical and mental quality of life and lower levels of depression after completing cardiac rehabiliation.[12] Additionally, in another study of 522 coronary patients undergoing cardiac rehabilitation, depressive symptoms decreased 63% after cardiac rehabilitation.[13]

1.2.5 Exercise Measures and Functional Capacity

Measures of exercise and functional capacity have also shown improvement after cardiac rehabilitation participation. A systematic review and metanalysis of 13 trials including 3990 individuals with heart failure found that completion of cardiac rehabilitation was associated with an increase in disease specific quality of life (Minnesota Living with Heart Failure) and 6 min walk test distance at 12 months.[14] In patients undergoing cardiac rehabilitation post-STEMI

(n=100), exercise capacity and 6-min walk distance was observed to have increased by 1 METand 75 meters, respectively.[15]

Overall, participation in a cardiac rehabilitation program has been shown to be associated with decreased mortality, decreased all-cause and cardiac hospitalization rates, reinfarction rates, improved mental and physical quality of life ratings, lower levels of depression, and improved exercise capacity.

1.3 Current Cardiac Rehabilitation Referral, Enrollment, and Completion Rates

Despite the guideline recommendations and demonstrated benefits, cardiac rehabilitation participation rates remain low. There are several explanations that may account for low CR participation rates. Participation in cardiac rehabilitation after a cardiovascular event requires provider referral. Referral rates are suboptimal with variation across diagnoses. When evaluating over 105,000 cardiac rehabilitation eligible patients from the Get with the Guidelines cohort from 2005-2014 with a diagnosis of heart failure, only 10.4% received CR referral at discharge from the hospital.[16] In the Get with the Guidelines Coronary Artery Disease registry of claims data from nearly 49,000 patients, 40% of eligible patients received referral for cardiac rehabilitation.[17] Higher referral rates are seen for individuals with a procedural diagnosis. In a large national cohort of patients undergoing percutaneous coronary intervention from the National Cardiovascular Data Registry of over 1.4 million patients, the cardiac rehabilitation referral rate was 59.2%.[18] The higher rate of referral for procedural diagnoses was seen in another Get with the Guidelines cohort of approximately 72,000 individuals with myocardial infarction, percutaneous coronary intervention, or coronary artery bypass grafting. In this cohort,only 56% of those eligible for cardiac rehabilitation were referred but rates were higher for thosewith coronary artery bypass grafting and percutaneous coronary intervention compared tomyocardial infarction (74% vs. 58% vs. 53%).[19]

Among the patients that are referred, only a portion enroll or participate in cardiac rehabilitation. Using administrative data of patients hospitalized for myocardial infarction, percutaneous coronary intervention, or coronary artery bypass grafting from 2007-2011 from the Veteran's Affairs Hospital and a 5% Medicare sample, there was a 16.3% (n=~143,000) participation rate in Medicare patients and 10.3% (n=~88,000) in Veteran's Affairs Hospital patients.[20] There are similar differences in enrollment for procedural vs. non-procedural diagnoses as seen for referrals; in an analysis of Medicare claims of patients >65 years old who experienced hospitalization for acute myocardial infarction or coronary artery bypass grafting (n=267,427), only 13.9% of acute myocardial infarction patients and 31.0% of coronary artery bypass grafting patients underwent cardiac rehabilitation. [21] An entirely surgical cohort of 201 patients undergoing valvular surgery and coronary artery bypass grafting in Olmsted County from 1996 to 2007 had a 47% participation rate in cardiac rehabilitation with an temporal increase in cardiac rehabilitation participation rates over time.[7] In the same county, in a registry of 2395 individuals undergoing percutaneous coronary intervention cardiac rehabilitation participation occurred in 40% of the cohort.[22] Similar rates were seen in a cohort of 16,935 Medicare beneficiaries undergoing open valve surgery in the US in 2014 with 43.2% enrolled incardiac rehabilitation.[23] While a study looking at ~158,000 Medicare beneficiaries in 2008 with myocardial infarction found a much lower rate of participation with only 14% attending cardiac rehabilitation within 1 year of diagnosis.[24] In addition to the enrollment rates, time to initiation and rates of completion are also suboptimal. In 2016, only 24.4% of about 366,000 Medicare beneficiaries who were eligible for cardiac rehabilitation participated, among those who participated only 24.3% initiated within 21 days and 26.9% completed a full course of 36 ormore sessions.[25]

1.4 Factors associated with Decreased Cardiac Rehabilitation Participation

Given the low rates of participation in cardiac rehabilitation, there have been multiple studies evaluating predictors of participation. Various provider, patient, and system level factors have been studied for their association with cardiac rehabilitation referral and participation including race, sex, presence of comorbidities, socioeconomic status, neighborhood, age, qualifying diagnosis, and regional location.

1.4.1 Race

Racial and ethnic differences are seen across cardiac rehabilitation referral, enrollments, and participation rates with nonwhite patients typically experiencing inferior rates compared to white patients. Disparities in referrals were seen in the Get with the Guidelines coronary artery disease registry of nearly 49,000 patients with Black, Hispanic, and Asian patients 20%, 36%, and 50% less likely to receive referral than white patients.[17] Similar disparities were seen in enrollment rates, when compared to white patients (n=~17,000 Medicare beneficiaries), several racial and ethnic groups had lower odds of enrolling in cardiac rehabilitation including Black (OR 0.6), Asian (0.36), and Hispanic (0.36) patients.[23] In patients referred for cardiac rehabilitation white patients initiated rehabilitation more often than non-white patients (OR 1.78)with persistent effects even after adjustment for individual factors.[26] In Medicare beneficiaries (n=~366,000) who were eligible for cardiac rehabilitation participation was lower among Hispanic (prevalence ratio 0.63) and non-Hispanic Blacks (prevalence ratio 0.70) compared to non-Hispanic whites.[25]

1.4.2 Sex

Sex has been identified as a predictor of cardiac rehabilitation participation. Women are less likely to be referred to or enroll in cardiac rehabilitation programs. In meta-analysis of 19 observational studies reporting data for 241,613 participants, women were significantly less likely to be referred to a cardiac rehabilitation program (OR 0.68).[27] Another meta-analysis evaluated cardiac rehabilitation enrollment with 26 eligible studies reporting data on 297,719 participants; women were also significantly less likely to be enrolled in cardiac rehabilitation (OR 0.64).[28] These differences have been identified in numerous studies.[17–19,29,30] There is also an interaction between race and sex. A study of 253 women with cardiac rehabilitation eligible diagnoses had an enrollment rate of only 15% with black women in particular 55% less likely tobe referred for cardiac rehabilitation and 58% less likely to enroll.[31] These differences in referraland enrollment translate to outcomes; women who receive cardiac rehabilitation referral at hospital discharge have significantly lower mortality compared to those who do not (OR 0.61).[17]

1.4.3 Comorbidities

Both the presence of specific comorbidities and having multiple comorbidities play a role in cardiac rehabilitation participation. Individuals with diabetes referred to cardiac rehabilitation are 26% less likely to complete cardiac rehabilitation than those without diabetes when evaluating national administrative data.[32] Similarly, in Olmsted County, lack of diabetes was associated with increased cardiac rehabilitation participation (OR 2.5).[33] The Get with the Guidelines cohort found that those who were referred to cardiac rehabilitation were more likely to have fewer comorbid conditions, while an analysis of Medicare claims similarly found that those who completed cardiac rehabilitation were more likely to have fewer comorbidities.[16,21]

1.4.4 Individual Socioeconomic Status

While analyses have shown that cardiac rehabilitation programs are cost-effective, a full course of cardiac rehabilitation consists of 36-sessions which requires multiple co-pays as well as other costs associated with attending cardiac rehabilitation including missed work or transportation costs.[34] The mean cost of cardiac rehabilitation in Medicare beneficiaries was $103 per session with an average out of pocket cost of $23 per session.[25] Individual socioeconomic status plays a role in prediction of cardiac rehabilitation participation. Access to insurance is a significant predictor of cardiac rehabilitation participation with those who have insurance more likely to complete all 36-sessions.[35] In a study of 1809 patients in Ontario, whenindividuals eligible for cardiac rehabilitation were stratified above and below a median socioeconomic status score. Those with low socioeconomic status had lower rates of referral (61.4% vs. 68.1%), enrollment (51.6% vs. 60.2%), and participation (50.3% vs. 56.1%).[30]

1.4.5 Neighborhood Location

Individual residence plays a complex role in cardiac rehabilitation with multiple factors including neighborhood socioeconomic status, distance to cardiac rehabilitation facility, urban vs. rural setting, and distance to hospital impacting participation rates. In an analysis of Medicare claims for acute myocardial infarction or coronary artery bypass grafting, longer distance to cardiac rehabilitation was associated with decreased cardiac rehabilitation use with those who were >15 miles from a cardiac rehabilitation facility having a 71% lower odds of utilizing cardiac rehabilitation.[21] Distance to a hospital was evaluated in a cohort of cardiac rehabilitation-eligible individuals, those who lived >30 minutes from a hospital completed fewer cardiac rehabilitation sessions despite similar referral and enrollment rates.[30] Additionally, the socioeconomic status of neighborhood impacts cardiac rehabilitation participation with those living in the most deprived neighborhoods less than half as likely to initiate cardiac rehabilitation(OR 0.42).[36] In an analysis of Medicare claims of patients with acute myocardial infarction or coronary artery bypass grafting, patients living in zip codes with higher levels of urbanization and poverty were 36% and 17% less likely to use cardiac rehabilitation; while patients with the highest median household income and education were 23% and 33% more likely to use cardiac rehabilitation.[21]

1.4.6 Age

Multiple studies have included age in the analysis of predictors of cardiac rehabilitation. Older age is associated with decreased rates of referral to, initiation of, and level of participation in cardiac rehabilitation. The Get With The Guidelines cohort of ~105,000 cardiac rehabilitation eligible patients found those with an older age were less likely to be referred.[16] Older Medicare beneficiaries eligible for cardiac rehabilitation after acute myocardial infarction were less likely to receive cardiac rehabilitation.[22] In another cohort of ~366,000 Medicare beneficiaries in 2016,level of participation was lower with older individuals. [25]

1.4.7 Hospital Variation

There is significant between-hospital variation in cardiac rehabilitation participation rates which may reflect differences in referral programs or practices. In the National Cardiovascular Data Registry of patients undergoing percutaneous coronary intervention, there were many institutional characteristics that were strongly associated with increased referral to cardiac rehabilitation including: regional differences such as Midwest Region vs. other regions (OR 7.36), larger hospital size, and private/community hospitals vs. teaching (OR 2.33).[18] Using administrative data of hospitals with patients hospitalized for myocardial infarction, percutaneous coronary intervention, or coronary artery bypass grafting there was significant hospital variation between Medicare hospitals with participation rates ranging from 3% to 75% and VA hospitals with participation rates ranging from 1% to 43%.[20] In Olmsted County, individuals with an in-hospital cardiologist provider were significantly more likely (OR 18.82) to have cardiac rehabilitation referral.[33]

1.4.8 Qualifying Diagnosis Type

Multiple studies have identified the qualifying diagnosis as a predictor of cardiac rehabilitation participation with procedural diagnoses generally associated with higher rates of referral and participation. In a study of ~366,000 Medicare beneficiaries there were stark differences between participation rates in cardiac rehabilitation by qualifying event type with 53.3% of those with coronary artery bypass grafting participating vs. only 7.1% of those with acute myocardial infarction.[25] This finding was replicated in a number of other cohorts includingthe Get with the Guidelines cohort of cardiac rehabilitation eligible patients where those with an in-hospital procedure were more likely to be referred to cardiac rehabilitation with higher rates for coronary artery bypass and percutaneous coronary intervention compared to myocardial infarction (74% vs. 58% vs. 53%).[16,19] In Medicare beneficiaries undergoing open valve surgeryin the United States in 2014, those undergoing concomitant coronary artery bypass grafting had a26% higher odds of enrollment in cardiac rehabilitation.[23] In an analysis of Medicare claims of patients >65 years old with hospitalization for coronary artery bypass grafting or acute myocardial infarction, coronary artery bypass grafting was associated with higher rates of cardiac rehabilitation with 31.0% vs. 13.9%.[21]

Overall, there are multiple predictors of decreased cardiac rehabilitation referral and participation including nonwhite race, Hispanic ethnicity, female sex, presence of multiple comorbidities, poorer socioeconomic status, increased distance from cardiac rehabilitationfacility or rural setting, increased age, and non-procedural qualifying diagnosis.

1.5 Initiatives to Increase Cardiac Rehabilitation Enrollment

Given the suboptimal cardiac rehabilitation participation rates, there have been national initiatives to increase rates. In 2008, due to the low enrollment in cardiac rehabilitation programs for individuals with myocardial infarction, Get with the Guidelines initiated a clinical pathway for referral and enrollment.[37] A few years later, the Million Heart Initiative was launched in 2012 and renewed in 2017 with a goal of increasing cardiac rehabilitation participation rates from ~20% to 70% which is estimated to prevent 1 million cardiovascular events.[4,38] The initiative is additionally estimated to save ~25,000 lives and prevent 180,000 hospitalizations.[4] The initiative combines automatic electronic health record referrals with an opt out option, use ofcardiac rehabilitation participation as a quality measure, inclusion of home-based cardiac rehabilitation, flexible hours of operation for cardiac rehabilitation, and referral prior to discharge from the hospital.[4]

In addition to the Get with the Guidelines and Million Hearts initiatives to increase referrals, there has also been a push to increase alternative delivery methods of cardiac rehabilitation to make it more accessible. During the COVID-19 pandemic, gaps in cardiac rehabilitation care have worsened given the decreased availability of on-site cardiac rehabilitation services.[39] Home-based cardiac rehabilitation is a potential alternative and the gapsin care during the pandemic provide an impetus to increase availability of alternative methods. Inindividuals who decline traditional cardiac rehabilitation, home-based mobile cardiac rehabilitation was safe and beneficial with demonstrated improvements in VO2 peak.[40] When compared to facility-based cardiac rehabilitation, home-based alternatives lead to greater 3-month functional gains.[41] The American Association of Cardiovascular and Pulmonary Rehabilitation, American Heart Association, and American College of Cardiology have issued ajoint statement emphasizing that home-based cardiac rehabilitation programs which rely on remote coaching and indirect exercise supervision have been successfully deployed in the UK and Canada and they provide guidance for implementation in the United States.[42]

Finally, digital health interventions provide potential for increasing access to cardiac rehabilitation. They have been studied primarily in conjunction with traditional cardiac rehabilitation but may also have the potential to be used as the primary mode of delivery. Theuse of digital health interventions in conjunction with traditional cardiac rehabilitation are associated with significant improvements in weight loss and may be a method to decrease rehospitalizations.[42]

1.6 Gaps in the Literature

While there have been clear disparities in cardiac rehabilitation completion rates by race, with nonwhite individuals having lower rates of cardiac rehabilitation completion, it is possible that there is an interaction between race and other demographic or socioeconomic factors. Thereis a paucity of data regarding the impact of social and socioeconomic factors such as occupation, education level, household income, household composition, and sex on racial differences.

Additionally, there are limited data regarding cardiac rehabilitation participation measures of initiation and adherence, by race, including: mean days to initiation, percentage initiated within 21 days of event, percentage with any cardiac rehabilitation, percentage completing at least 25 sessions cardiac rehabilitation, and percentage completing a full course of cardiac rehabilitation.

1.7 Public Health Significance

It has been demonstrated that cardiac rehabilitation participation and completion is associated with reduced morbidity and mortality in cardiovascular patients however the rates of participation are suboptimal with disparities by race. Understanding the socioeconomic drivers of racial disparities in cardiac rehabilitation can provide targets for interventions to improve access to cardiac rehabilitation in this vulnerable population. Additionally, understanding the dynamics of cardiac rehabilitation referral, enrollment, initiation, and adherence by race will inform where the gaps in the pathway are occurring. This information is critical to providing targets for public health interventions.

1.8 Objectives of Current Study

The aim of this current study is 1) to determine the proportion of patients hospitalized with cardiac rehabilitation-eligible diagnoses who participated in cardiac rehabilitation, overalland by race 2) to evaluate the socioeconomic and demographic factors associated with participation in cardiac rehabilitation stratified by race, 3) to evaluate measures of cardiac rehabilitation initiation and adherence in those who complete cardiac rehabilitation by race to further identify gaps. To accomplish these aims we will use Optum electronic health record claims data from numerous hospital systems across the United States from 2016-2019.

We hypothesize that there will be low rates, <30%, of cardiac rehabilitation participation across all eligible diagnoses with particularly low rates in the "non-procedural" diagnoses.

Additionally, we hypothesize that individuals with black race will have lower rates of cardiac rehabilitation participation than white counterparts with social and socioeconomic factors moderating these differences. Finally, we hypothesize that social factors of education level and household income interact with race to moderate differences in participation.

2.0 Methods

2.1 Study Data and Cohort

Our study is a retrospective cohort study using administrative claims data. Data were obtained from Optum Clinformatics Data Mart (Eden Prairie, Minnesota, www.optum.com), a

deidentified administrative claim database including claims data from recipients of a commercialhealth insurance and Medicare Advantage (C and D). The database is updated annually and spans all 50 states providing a geographically representative sample. From initiation in 1993 to the present day, the database has claims from over 111 million individuals. Medical claims include diagnosis and procedure codes from the *International Classification of Diseases, Ninth and Tenth Revisions (ICD-9* and *ICD-10)* and/or Current Procedural Terminology.

We identified adult (age >18 years old) patients in the database with an incident hospitalization for a cardiac rehabilitation qualifying diagnosis using *ICD* or *CPT* codes between 1/1/2016 and 12/31/2018. Cardiac rehabilitation eligible diagnoses included: 1) Acute Myocardial Infarction (AMI) listed as first or second diagnosis, 2) Coronary Artery Bypass Grafting (CABG) surgery, 3) Valve Repair or Replacement, 4) Percutaneous Coronary Intervention (PCI), Heart Transplant, or Heart-Lung Transplant. The *ICD-9*, *ICD-10*, and *CPT* codes used for the cardiac rehabilitation qualifying diagnoses are listed in **Appendix Table 1**.

Incident qualifying events were defined as a first qualifying event within 6 months with continuous enrollment in the database for at least 6 months prior to the event. We used incident events to minimize individuals who would have already enrollment in or completed cardiac rehabilitation. Individuals were excluded if they disenrolled within 90 days of discharge. We excluded patients who were discharged to a skilled nursing facility or hospice care. We also excluded patients who were missing data on race. The date of study entry was defined as the discharge date from hospitalization of qualifying diagnosis. Our final analytic sample included 121,963 individuals. **Figure 1** summarizes the numbers included and excluded in our study. The characteristics of those in the final analytic sample were compared to those excluded to assess differences in missing data.

2.2 Covariates

Age, sex, and race are included in the claims data linked to individual patient enrollment data. The database collects race/ethnicity from public records, such as driver’s license records, with the remaining data imputed using commercial software (E-tech, Ethnic Technologies, South Hackensack, New Jersey) with a validated method.[43] Race and ethnicity were subsequently categorized as Asian, Black, White, or Hispanic. This method of imputation has been shown to have moderate sensitivity (48%) but higher specificity (97%) and positive predictive value (71%) for identifying Black individuals.[43] Sex was categorized as Female, Male, or Unknown. Age, in years, is reported as the age at the time of incident hospitalization.

Education level was estimated based on median census block data and categorized as: <12th grade, high school diploma, <bachelor’s degree, bachelor’s degree, and unknown. Additional socioeconomic data, including median household income and household net worth, were available through zip-code + 4 linked enrollment data from the U.S. Census Bureau. Householdincome was categorized as: <$40,000, $40,000-49,999, $50,000-59,999, $60,000-74,999, $75,000-99,999, >$100,000, and unknown. Household net worth was categorized as: <$25,000, $25,000-149,999,

$150,000-249,999, $250,000-499,999, >$500,000, and unknown. Clinical covariates were selected to include Hypertension, Diabetes, and Ischemic Stroke.These covariates were selected to determine individuals' impact on cardiac rehabilitation participation. All covariates were defined by *ICD-9* or *ICD-10* codes in claims prior to or at the time of the incident hospitalization. The codes used to define these conditions are shown in **Appendix Table 1.** The Elixhauser Comorbidity Index, a validated index to predict hospital useand mortality, was used to adjust for overall comorbid conditions.[45] The components of the Elixhauser Comorbidity Index were extracted using *ICD* codes and a composite Elixhauser Comorbidity Index was calculated using a previously described coding algorithm.[44] The diagnoses used in the Elixhauser, the relative weights for each comorbidity, and the *ICD* codes used are summarized in **Appendix Table 2.** It is important to note that our selected clinical covariates of hypertension, diabetes and ischemic stroke carry a weight of 0 in the Elixhauser and thus do not impact the score.

2.3 Outcomes

Our primary outcome was defined as any participation (≥ 1 session) in cardiac rehabilitation in the 1-year period following the cardiac rehabilitation diagnosis. The primary outcome was identified using billing codes which are summarized in **Appendix Table 1.**

Secondary outcomes among those who participated in any cardiac rehabilitation included: time to initiation of cardiac rehabilitation, number of cardiac rehabilitation sessions used, completion of ≥25 CR sessions, and completion of a full course of cardiac rehabilitation (at least 36 sessions). Time to initiation was defined in days from the discharge date of the qualifying hospitalization to the initial cardiac rehabilitation session.

2.4 Statistical Analysis

We examined the cardiac rehabilitation participation rates for the overall sample, and by race, gender, age, education level, household income, household net worth, and clinical characteristics. We reported rates among eligible, those completing all 36 sessions, those completing at least 25 sessions, the median number of sessions completed, and time to initiation.

Differences in characteristics across cardiac rehabilitation participation status (any participation vs. no participation) were compared using χ^2 tests for categorical variables including race, income, and education. Differences in time to initiation of cardiac rehabilitation by characteristic were assessed using the Kruskal-Wallis or Wilcoxon rank sum tests for non-normally and normally distributed, respectively, continuous characteristics.

Odds of enrolling in cardiac rehabilitation by clinical characteristics were estimated using logistic regression models. Model 1 adjusted for race, age, and sex. Model 2 adjusted for variables in model 1 + Elixhauser score, hypertension, diabetes, and ischemic stroke. Model 3 adjusted for variables in model 2 + income. Model 4 was a fully adjusted model including race, age, sex, Elixhauser score, hypertension, diabetes, ischemic stroke, income, education and qualifying diagnosis type.

To assess the interaction of social factors and race, two additional models were run with interaction terms for race. Model 4a adjusted for Model 3 + interaction of race and household income. Model 4b adjusted for Model 4 + interaction of race and education.

We assessed CR adherence across groups by comparing e the number of individuals who completed all 36 sessions, those completing at least 25 sessions, and the median number of sessions for race and each sociodemographic and clinical characteristic. Number of sessions was compared, by sociodemographic and clinical characteristics, using ordinal logistic regression. Sensitivity analysis was performed evaluating initiation and adherence only among those who had enrollment for at least one year.

3.0 Results

3.1 Cohort

There was a total of 121,963 individuals included in the final cohort for analysis. Of the cardiac rehabilitation eligible participants, 25.7% (n=31,371) had any participation in cardiac rehabilitation. The characteristics of the final analytic cohort stratified by those participating in cardiac rehabilitation vs. those not participating are summarized in **Table 1.** Our final analytic sample was on average 70 years old, 62.3% male, 75.1% of white race, 11.7% with a bachelor's degree or higher, 31.5% with a household income <40K, 92.6% with hypertension, and 50.4% with diabetes. **Appendix Table 3** summarizes the comparison of those in the analytic sample vs. those excluded for missing race. Individuals with missing data for race were more likely to have valve repair or coronary artery bypass grafting and less likely to have myocardial infarction as a qualifying diagnosis, had higher levels of education, and increased household net worth and income.

3.2 Participation Rates

Table 2 summarizes the cardiac rehabilitation participation rates and time to initiation by clinical and sociodemographic characteristics. There were significant differences in cardiac rehabilitation participation rates by race with 28.8% of White individuals participating, compared to 22.4% of Asian individuals, 16.9% of Black individuals, and 14.1% of Hispanic individuals (p<0.0001). There were differences in participation rates by qualifying diagnosis with 6.4% of those with myocardial infarction only participating in cardiac rehabilitation compared to higher rates for the procedural diagnoses with Coronary Artery Bypass Grafting 48.6%, Valve Repair/Replacement 37.9%, PCTA/stent 27.2%, and Heart Transplant 25.4% (p<0.0001). Those who participated in cardiac rehabilitation vs. those who did not were younger on average (67.6 vs. 70.9 years old, p<0.0001). Male sex was associated with a higher cardiac rehabilitation participation rate than female sex (29.2% vs. 20.1%). Those with higher educationlevels had higher participation rates with 5.7% of those with <12th grade education participatingcompared to those with a bachelor's degree participating 35.0% of the time (p<0.0001). Both higher household income and household net worth were associated with a higher rate of participation in cardiac rehabilitation in a graded fashion with 17.1% of those with a household income of <$40,000 participating and 38.0% of those with household income >$100,000 participating (p<0.001).

3.3 Time to Initiation

Among those who participated in cardiac rehabilitation (n=31,557), the median time to initiation for cardiac rehabilitation among participations was 33 days (IQR 19,55). White individuals had a median time to initiation of 32 days compared to longer times to initiation for Asian, Black and Hispanic individuals of 38, 42, and 39 days, respectively, p<0.001. Women initiated cardiac rehabilitation later than men (36 days vs. 32 days, p<0.001). Those with a bachelor's degree initiated cardiac rehabilitation with a median of 35 days compared to those with <12th grade with a median of 45 days, p<0.001. The time to initiation across household networth and income were similar.

3.4 Adherence

Measures of cardiac rehabilitation adherence, including median number of sessions, % completing at least 25 sessions, and number completing a full course of cardiac rehabilitation, by clinical and sociodemographic characteristic are summarized in **Table 3**. Of those participating in cardiac rehabilitation, the median number of sessions was 10 (IQR 3,30) with only 29.9% of those who initiated completing ≥ 25 sessions and 14.3% completing the full course of 30sessions.

Black individuals had similar measures of adherence to their White counterparts including median number of sessions completed (11, (IQR 3,33) for Blacks and 10 (IQR 3,30) for Whites and % completing a full course (15.7% for Blacks and 14.3% for Whites). Asian andHispanic individuals had lower measures of adherence with median days completed of 6 (IQR 3,25) for each group and % completing a full course of 12.3% for Asian individuals and 12.0% for Hispanic individuals.

Higher household net worth, but not household income, was associated with a graded increase in number of sessions completed with those with a household net worth of <$25,000 completing a median of 6 sessions (IQR 3,24) while those with a net worth of >$500K completing a median of 14 days (IQR 4,33). **Figure 2** demonstrates the association of higherhousehold net worth with increased number of sessions attended in a graded fashion.

3.5 Predictors of Cardiac Rehabilitation Participation

We observed significant sex, race, education, income, comorbidity, and procedure type differences in odds of cardiac rehabilitation participation that persisted in all models. The adjusted odds ratios and 95% Wald Confidence Intervals from the fully adjusted model (model 4) is summarized in **Table 4.**

Compared to White individuals, Black, Hispanic, and Asian individuals were 25%, 52%, and 45% less likely to have cardiac rehabilitation participation, ($p<0.0001$). Females were 7% less likely than males to participate in cardiac rehabilitation, (OR 0.93, 95% CI 0.96-0.90, $p<0.0001$). Presence of comorbidities including stroke, hypertension, and diabetes were associated with a 10%, 17%, and 23% lower odds of cardiac rehabilitation participation, ($p<0.0001$). When compared to individuals with income >$100,000, those with lower income ($40,000-49,999, $50,000-59,999, $60,000-74,999, $75,000-99,999) had decreased cardiac rehabilitation participation in a graded fashion with 31%, 27%, 19%, and 6.5% lower odds of participation, ($p<0.0001$). Compared to bachelor's degree, less education was associated with lower odds of participation in those with <12th Grade Education (OR 0.26, 95% CI 0.19-0.38, $p<0.0001$), High School Diploma (OR 0.65, 95% CI 0.61-0.68, $p<0.0001$), and Some College (OR 0.89, 95% CI 0.85-0.93, $p<0.0001$). Procedural qualifying diagnoses were associated with higher odds of cardiac rehabilitation participation compared to acute myocardial infarction in CABG vs. MI (OR 12.5, 95% CI 11.11-12.50, $p<0.0001$), PCTA/Stent vs. MI (OR 4.35, 95% CI 4.00-4.55, $p<0.0001$), Transplant vs. MI (OR 4.0, 95% CI 3.23-5.00, $p<0.0001$), and Valve Repair vs. MI (OR 5.0, 95% CI 4.76-5.26, $p<0.0001$).

3.6 Interaction of Social Factors and Race in Cardiac Rehabilitation Participation

We demonstrated that non-white race, lower education level, and lower household income was associated with decreased cardiac rehabilitation participation. We also evaluated, using models with interaction terms for race and education and race and income, whether the effect of race was modified by social factors. **Figure 3** summarizes the logistic regression models evaluating the impact of social factors on race (Model 4a and 4b). When evaluating for the interaction of race and social factors we found there was a significant interaction between both race and education ($p = 0.0059$) and race and income ($p=0.0158$). At lower incomes (<$40,000 and $40,000-49,999), Asian individuals were more likely than White individuals to participate in cardiac rehabilitation but less likely to participate then White individuals at higherincomes. Black and Hispanic individuals were less likely to participate in cardiac rehabilitation than white individuals at all income levels but with a greater effect at higher income levels.

Similarly, there was an interaction between race and education on cardiac rehabilitation participation. Asian individuals were more likely than white individuals to participate in cardiac rehabilitation at lower levels of education (<12th grade and high school diploma) but less likely at higher levels. Black individuals had higher rates of cardiac rehabilitation compared to White individuals at the lowest level of education but as education level increases Black individuals had decreasing odds compared to White individuals.

4.0 Discussion

In a large geographically and racially diverse cohort of individuals we found, using health claims data, the cardiac rehabilitation participation rate among those hospitalized with a qualifying diagnosis was 25.7%. Compared to White individuals, Black, Hispanic and Asian individuals were 25%, 52%, and 45% less likely to participate in cardiac rehabilitation, even after adjustment for sociodemographic and clinical covariates. Additionally, female sex, presenceof comorbidities, less education, lower household income and net worth, and acute myocardial infarction as a qualifying diagnosis were all associated with lower cardiac rehabilitation participation rates. Household net worth was significantly associated with total number of days completed of cardiac rehabilitation while household income was not. When evaluating for the impact of social factors on racial differences in cardiac rehabilitation participation, we found thatthere was a significant interaction of race and education and race and income. For both educationand income, as the level increased non-white individuals were less likely to participate in cardiacrehabilitation than white individuals.

The finding of a cardiac rehabilitation participation rate of 25.7% is consistent with previous work including a 2016 study of ~366,000 Medicare beneficiaries eligible for cardiac rehabilitation that found a participation rate of 24.3%.[25] The confirmation of the suboptimal cardiac rehabilitation participation rate indicates room for improvement to increase cardiac rehabilitation participation use overall. Our study adds to the growing body of evidence that nonwhite minorities, females, individuals with a nonprocedural qualifying diagnosis, and those with increased comorbidities experience lower cardiac rehabilitation participation rates. Future studies may also consider a procedure-specific analysis or an analysis excluding the heart transplant patients. Heart transplant patients, due to the etiology of their disease tend to be younger, may have more resources focused on their post-operative course, and have a longerpost-operative recovery time than the other qualifying diagnoses.

While previous work has related low individual socioeconomic status and lack of access to insurance to decreased cardiac rehabilitation participation rates,[30,35] our study adds novelty by evaluating specifically household income, household net worth, and education level. Household net worth is an important marker of socioeconomic status that captures unique aspects of socioeconomic status not necessarily captured with household income. In an older population, it is possible individuals who are retired or not actively employed may have a higher household net worth but a lower or absent household income. Additionally, individuals with a higher household net worth may not be as affected by missed work associated with participation in cardiac rehabilitation. This is possibly why we saw that higher household net worth, but not household income, was associated with an increase in number of days completed. Our study further expands on the current literature by evaluating the impact of social factors including household income and education level on racial differences in cardiac rehabilitation participation rates with both education and income significantly modifying differences. We found that effect of decreased cardiac rehabilitation participation in nonwhite minorities compared to white individuals was greater, in general, at higher income and education levels. With differences worsening at higher socioeconomic status levels, it suggests that increased socioeconomic status improves outcomes in white individuals more than their non-white counterparts.

One of the strengths of this analysis are that it included a large sample size using nationwide claims data of over 124,000 individuals. The sample was taken from a database that is geographically diverse which enhances generalizability. Additionally, we used data from a sample that was racially and ethnically diverse with ~25% of the sample nonwhite.

Our study also has limitations worth noting. First, we excluded individuals missing data on race. Of the 189,316 individuals with continuous enrollment for at least 6 months there were 16,808 (8.9%) missing data on race. We did, however, compare those with missing data to the final analytic sample to evaluate differences and those who were missing data had slightly higher socioeconomic status. In addition to missing data on race, the race variable was imputed in the Optum database and while it had high positive predictive value (71%) and specificity (97%) for black race, this method only has been shown to only have moderate sensitivity (48%) so there is likely some misclassification by race. Second, since our study includes health claims data that, by definition, excludes the uninsured, we likely are underestimating the impact of low income and our results are not generalizable to the uninsured population. We did, however, have socioeconomic diversity in our sample with 31.5% of the population with a household income

<$40,000. Third, we relied on health claims data to determine qualifying diagnoses and covariates. Claims data exist primarily for billing and reimbursement and may incompletely capture individual conditions. We were unable to perform individual review of the health records for adjudication and thus there is likely some misclassification of diagnoses and covariates.

Fourth, we expect there is some residual confounding, in particular with unmeasured social variables such as health literacy. Fifth, increased distance to cardiac rehabilitation and rural location have been previously identified as factors associated with decreased cardiac rehabilitation participation however we are unable to measure these variables using administrative claims data. It is possible that these factors are impacting cardiac rehabilitation participation and we are unable to adjust for this effect. Sixth, in our study, we found that therewas a significant association between race and adherence to 25+ sessions. However, this is a controversial metric as a cutoff as the data are mixed on the dose-effect nature of cardiac rehabilitation. Finally, some of the variables (such as income, race, and education) were derived using algorithms which are subject to misrepresentation. For example, education level was determined by median of census block which does not account for areas that may have significant heterogeneity.

In our study of racial differences in cardiac rehabilitation participation it is important to note that there are many unmeasured variables that specifically impact racial differences in cardiac rehabilitation that are worth considering and addressing – racial/ethnic make-up of cardiac rehabilitation staff, availability of cardiac rehabilitation in primarily non-white communities and neighborhoods, and systemic racism. While these factors are more difficult to capture in an administrative claims database, recognizing the potential impact and addressing these differences is critical to improving cardiac rehabilitation participation in nonwhite minorities.

Our study supports prior evidence that cardiac rehabilitation participation rates are suboptimal and that multiple factors including race, sex, comorbidities, and social factors such as household income and education are associated with participation rates. Future studies that evaluate the impact of other social variables, such as health literacy or household composition, may further elucidate the social factors that interact with race leading to disparities in cardiac rehabilitation participation. The finding of household net worth, but not household income, being associated with adherence suggests that employment status may be associated ability to attend cardiac rehabilitation. Future studies that include employment status may help identify critical barriers to cardiac rehabilitation participation. While it is known that cardiac rehabilitation participation improves outcomes, it would also be informative to know the impact on outcomes specifically, by these social determinants of health and determine the degree to which cardiac rehabilitation participation improves outcomes in these populations.

Our work has important public health implications. In a contemporary, geographically and racially diverse cohort we found an overall suboptimal cardiac rehabilitation participation rate of 25.7%. Given that cardiac rehabilitation has a positive impact on morbidity and mortality, efforts to increase these participation rates overall has the potential to improve public health outcomes. Initiatives such as automatic electronic health record referral, virtual delivery options,increasing cardiac rehabilitation facilities in underserved or rural areas, community-based cardiac rehabilitation, or evening delivery options all have the potential to increased cardiac rehabilitation participation. While it was established that nonwhite race is a predictor of lower rates of cardiac rehabilitation participation, our study evaluated for social mediators. Education level and income are important social determinants of health that moderate the participation in cardiac rehabilitation. Incorporating these factors, in addition to race, into health care delivery systems provide an opportunity to address disparities and impact racial differences in cardiac rehabilitation. Additionally, we found that household net worth, but not household income associated with adherence; it is possible that cardiac rehabilitation programs that accommodate for individuals who cannot afford to miss work, such as evening hours or virtual options, may help increase adherence. Finally, assessing for and incorporating these social determinants of health in patients who are cardiac rehabilitation eligible provides a critical target for interventions to improve outcomes.

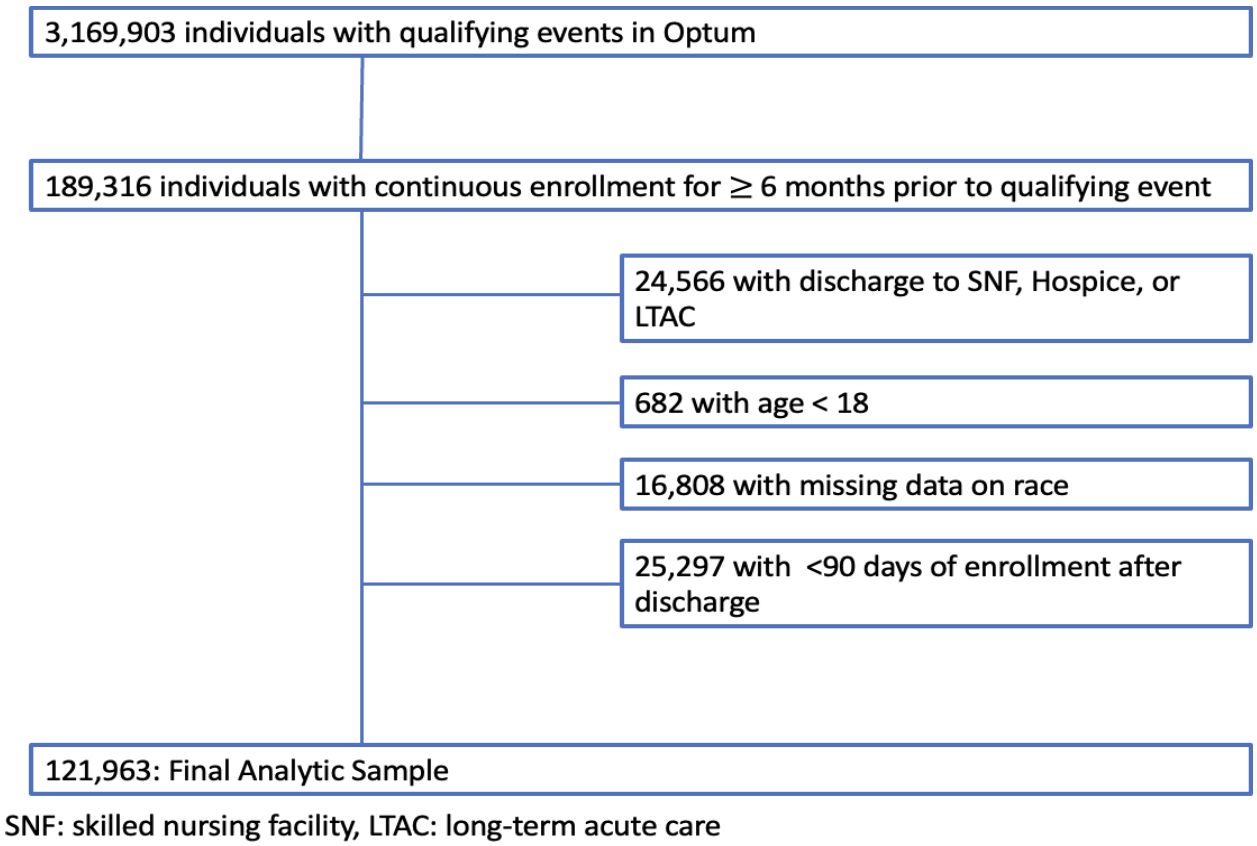


Figure 1. Inclusion and Exclusion Criteria

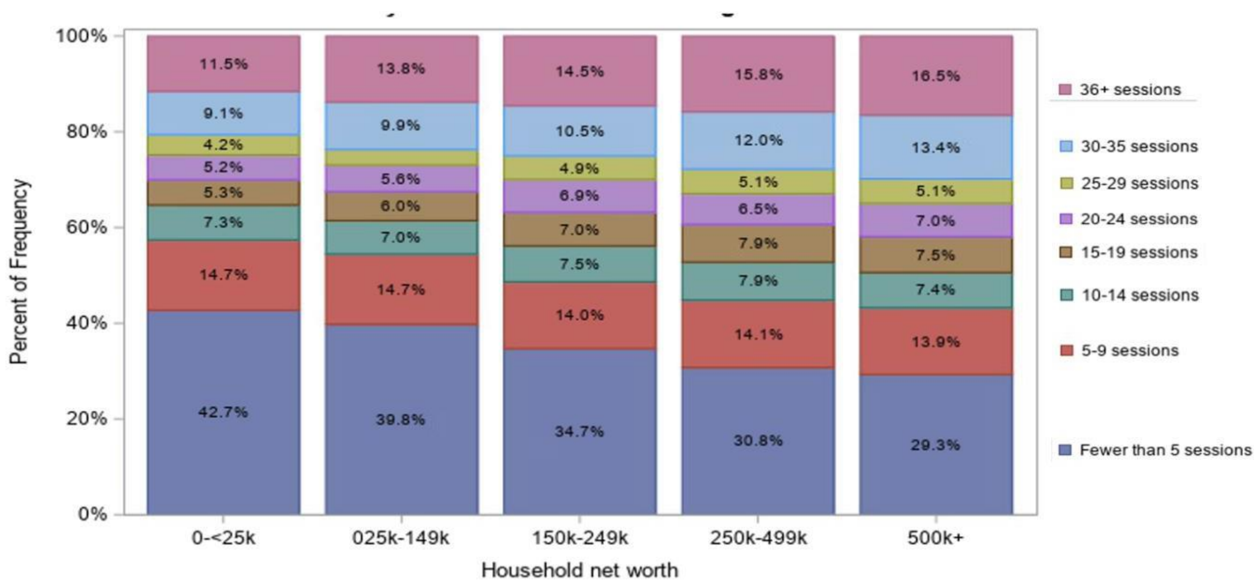
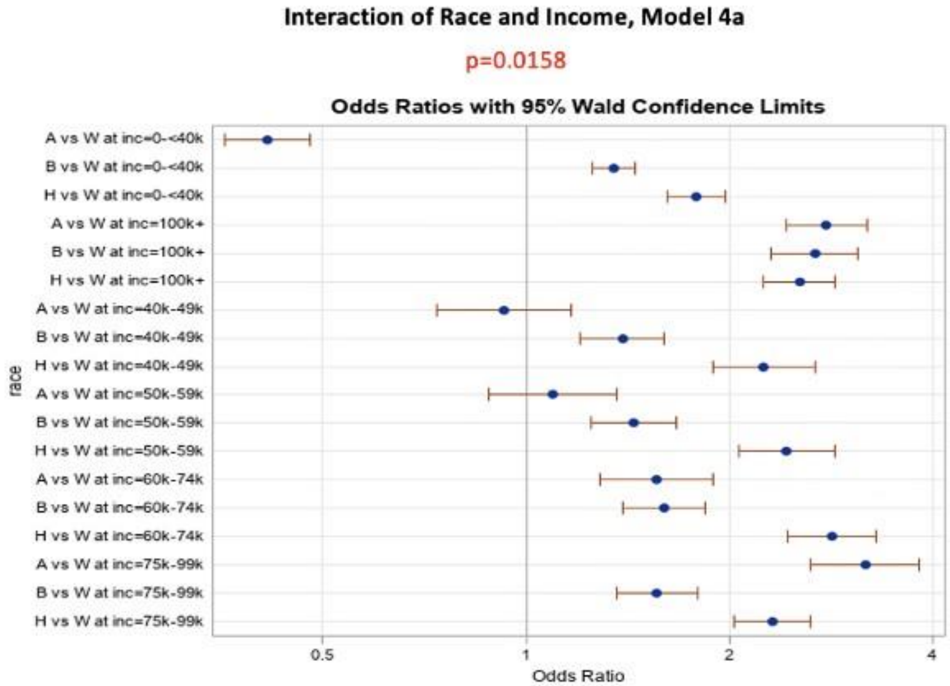


Figure 2. Cardiac Rehabilitation Attendance by Household Net Worth among those who initiated Cardiac Rehabilitation



A=Asian; B=Black; H=Hispanic; W=White; inc=income; educ=education

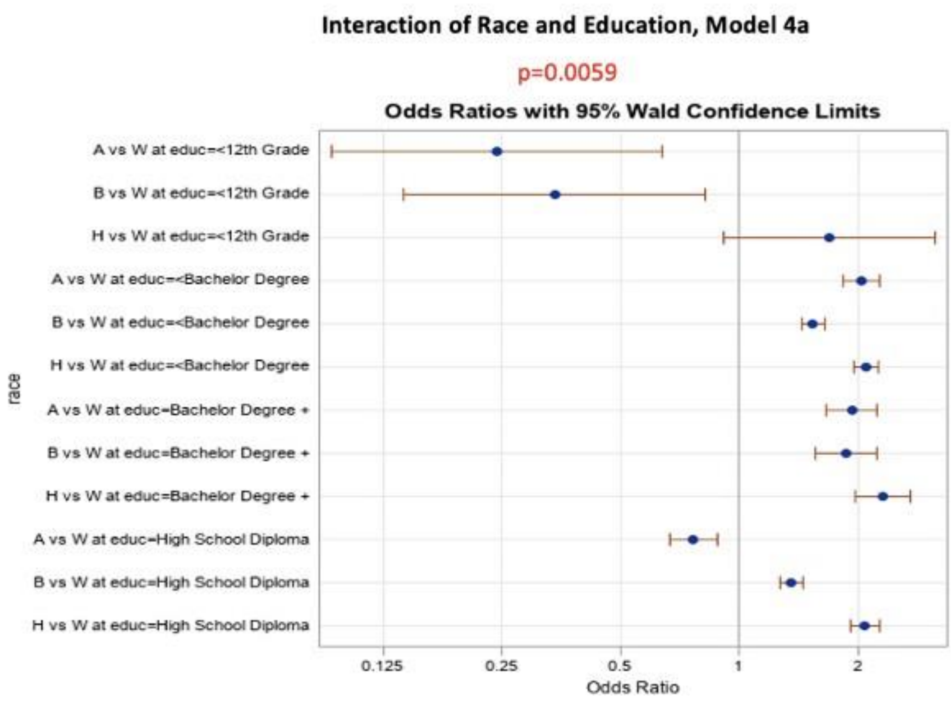


Figure 3. Cardiac Rehabilitation Odds of Not Participating, by Race and Social Factor Interaction

Table 1. Characteristics of Individuals with a Cardiac Rehabilitation Eligible Diagnosis, by participation in Cardiac Rehabilitation.

Characteristic	**All Qualifying Participants (n=121963)[1]**	**Cardiac Rehabilitation (n=31371) [2]**	**No Cardiac Rehabilitation (n = 90592)**
Cardiac Rehabilitation Qualifying Diagnosis			
Myocardial Infarction [3]	30615 (25.10%)	1973 (6.44%)	28642 (93.56%)
Coronary Artery Bypass Grafting	20978 (17.2%)	10195 (48.6%)	10783 (51.4%)
Valve Repair/Replacement	36549 (30.0%)	13856 (37.91%)	22693 (62.09%)
PCTA/stent	52130 (42.7%)	14200 (27.24%)	37930 (72.76%)
Heart Transplant	527 (0.4%)	134 (25.43%)	393 (74.57%)
Sociodemographic Characteristics			
Age at admission, mean (SD)	70.0 (11.8)	67.6 (11.4)	70.9 (11.9)
Sex			
Female, n (%)	45951 (37.68%)	9217 (20.06%)	36734 (79.94%)
Male, n (%)	76004 (62.32%)	22153 (29.15%)	53851 (70.85%)
Unknown, n (%)	8 (0.01%)	1 (0.0%)	7 (0.01%)
Race			
Asian, n (%)	3074 (2.52%)	687 (22.35%)	2387 (77.65%)
Black, n (%)	14732 (12.08%)	2496 (16.94%)	12236 (83.06%)
Hispanic, n (%)	12530 (10.27%)	1770 (14.13%)	10760 (85.87%)
White, n (%)	91627 (75.13%)	26418 (28.83%)	65209 (71.17%)
Education Level			
<12th Grade, n (%)	680 (0.56%)	39 (5.74%)	641 (94.26%)
High school diploma, n (%)	41677 (34.17%)	7658 (18.37%)	34019 (81.63%)
< Bachelor’s degree, n (%)	64950 (53.25%)	18603 (28.64%)	46347 (71.36%)
Bachelor’s degree +, n (%)	14299 (11.72%)	5001 (34.97%)	9298 (65.03%)
Unknown, n (%)	357 (0.29%)	70 (19.61%)	287 (80.39%)
Household Income			
<40k, n (%)	33918 (31.51%)	5807 (17.12%)	28111 (82.88%)
40k-49k, n (%)	9393 (8.73%)	2075 (22.09%)	7318 (77.91%)
50k-59k, n (%)	10171 (9.45%)	2416 (23.75%)	7755 (76.25%)
60k-74k, n (%)	13208 (12.27%)	3647 (27.61%)	9561 (72.39%)
75k-99k, n (%)	17206 (15.98%)	5587 (32.47%)	11619 (67.53%)

100k+, n (%)	23754 (22.07%)	9030 (38.01%)	14724 (61.99%)
Household Net Worth			
unknown, n (%)	14136 (11.59%)	2775 (19.63%)	11361 (80.37%)
<25k, n (%)	29975 (24.58%)	5286 (17.63%)	24689 (82.37%)
25k-149k, n (%)	22584 (18.52%)	5753 (25.47%)	16831 (74.53%)
150k-249k, n (%)	11660 (9.56%)	3362 (28.83%)	8298 (71.17%)
250k-499k, n (%)	17995 (14.75%)	5597 (31.1%)	12398 (68.9%)
500k+, n (%)	25613 (21%)	8598 (33.57%)	17015 (66.43%)
Clinical Characteristics			
Hypertension, n (%)	112992 (92.64%)	28093 (24.86%)	84899 (75.14%)
Diabetes, n (%)	61517 (50.44%)	13242 (21.53%)	48275 (78.47%)
Ischemic stroke/TIA, n (%)	47154 (38.66%)	11240 (23.84%)	35914 (76.16%)
Myocardial Infarction, n (%)	73490 (60.26%)	16113 (21.71%)	57377 (78.29%)
Elixhauser, median (Q1, Q3)	16 (7, 25)	13 (5, 21)	17 (8, 26)

[1] where patients were counted only for first qualifying event; event not limited to single type (ex: could have PCTA andCABG)

[2] where only CR after qualifying event was counted

[3] where pt only had AMI dx, no procedure codes during visit

Table 2. Cardiac Rehabilitation Participation and Initiation, by sociodemographic or clinical characteristic

	CR Eligible	Any CR Participation			
	N	N	Rate per 1000	% Among Eligible	Days to CR initiation, med (Q1,Q3)
Overall Total	121963	31557	258.74	25.87%	33 (19,55)
Age Groups					
18-44	3417	1063	311.09	31.11%	29 (17, 46)
45-54	9740	3135	321.87	32.19%	29 (16, 47)
55-64	22172	7043	317.65	31.77%	31 (17, 50)
65-74	39395	10904	276.79	27.68%	35 (20, 56)
75-84	33111	7551	228.05	22.81%	36 (20, 60)
85+	14128	1675	118.56	11.86%	35 (19, 63)
Gender					
Female	45951	9217	200.58	20.06%	36 (21, 61)
Male	76004	22153	291.47	29.15%	32 (18, 53)
Race/Ethnicity					
Asian	3074	687	223.49	22.35%	38 (23, 59)
Black	14732	2496	169.43	16.94%	42 (25, 69)
Hispanic	12530	1770	141.26	14.13%	39 (23, 63)
White	91627	26418	288.32	28.83%	32 (18, 53)
Education Level					
<12th Grade	680	39	57.35	5.74%	45 (23, 73)
High school diploma	41677	7658	183.75	18.37%	35 (20, 57)
< Bachelor's degree	64950	18603	286.42	28.64%	32 (18, 54)
Bachelor's degree +	14299	5001	349.74	34.97%	35 (20, 55)
Unknown	357	70	196.08	19.61%	29 (14, 43)
Household Income					
0 <40k	33918	5807	171.21	17.12%	35 (19, 60)

40k-49k	9393	2075	220.91	22.09%	32 (18, 54)
50k-59k	10171	2416	237.54	23.75%	32 (19, 53)
60k-74k	13208	3647	276.12	27.61%	33 (19, 54)
75k-99k	17206	5587	324.71	32.47%	32 (18, 53)
100k+	23754	9030	380.15	38.01%	34 (20, 53)
Household Net Worth					
unknown	14136	2775	196.31	19.63%	34 (19, 57)
<25k	29975	5286	176.35	17.63%	34 (19, 58)
25k-149k	22584	5753	254.74	25.47%	32 (18, 53)
150k-249k	11660	3362	288.34	28.83%	31 (18, 53)
250k-499k	17995	5597	311.03	31.10%	32 (18, 53)
500k+	25613	8598	335.69	33.57%	35 (20, 55)
Clinical Characteristics					
No hypertension	8971	3278	365.40	36.54%	26 (14, 44)
Hypertension	112992	28093	248.63	24.86%	34 (20, 56)
No diabetes	60446	18129	299.92	29.99%	31 (17, 50)
Diabetes	61517	13242	215.26	21.53%	37 (21, 61)
No ischemic stroke/TIA	74809	20131	269.10	26.91%	31 (17, 52)
Ischemic Stroke/TIA	47154	11240	238.37	23.84%	37 (22, 61)
No myocardial infarction	47750	15277	319.94	31.99%	36 (21, 56)
Myocardial infarction	74213	16113	217.12	21.71%	30 (17, 54)
Initial Qualifying Event Type					
AMI with procedure	43598	14160	324.79	32.48%	29 (16, 50)
AMI without procedure	30615	1973	64.45	6.44%	45 (22, 90)
CABG	20978	10195	485.99	48.60%	37 (23, 55)
Heart Valve Procedure	36549	13856	379.11	37.91%	36 (22, 56)
PCI	52130	14200	272.4	27.24%	28 (15, 50)
Heart Transplant	527	134	254.27	25.43%	60 (30, 98)

Table 3. Cardiac Rehabilitation Adherence, by sociodemographic and clinical characteristic

	N	36+ Sessions	25-35 Sessions	0-25 sessions	Number of Sessions, median (Q1, Q3)
Overall Total	29791	4250 (14.27%)	4658 (15.64%)	20883 (70.10%)	10 (3,30)
Age Groups					
18-44	951	22 (2.31%)	25 (2.63%)	904 (95.06%)	3 (2, 5)
45-54	2869	58 (2.02%)	104 (3.62%)	2707 (94.35%)	3 (2, 5)
55-64	6503	229 (3.52%)	320 (4.92%)	5954 (91.56%)	4 (2, 6)
65-74	10475	2026 (19.34%)	2162 (20.64%)	6287 (60.02%)	18 (5, 35)
75-84	7362	1609 (21.86%)	1701 (23.11%)	4052 (55.04%)	22 (8, 35)
85+	1631	306 (18.76%)	346 (21.21%)	979 (60.02%)	19 (6, 35)
Gender					
Female	8831	1267 (14.35%)	1536 (17.39%)	6028 (68.26%)	12 (4, 31)
Male	20959	2983 (14.23%)	3122 (14.9%)	14854 (70.87%)	9 (3, 29)
Race/Ethnicity					
Asian	644	79 (12.27%)	85 (13.2%)	480 (74.53%)	6 (3, 25)
Black	2360	370 (15.68%)	403 (17.08%)	1587 (67.25%)	11 (3, 33)
Hispanic	1653	198 (11.98%)	221 (13.37%)	1234 (74.65%)	6 (3, 25)
White	25134	3603 (14.34%)	3949 (15.71%)	17582 (69.95%)	10 (3, 30)
Education Level					
<12th Grade	34	2 (5.88%)	1 (2.94%)	31 (91.18%)	5 (3, 14)
High school diploma	7241	1074 (14.83%)	1097 (15.15%)	5070 (70.02%)	10 (3, 30)
< Bachelor’s degree	17686	2569 (14.53%)	2774 (15.68%)	12343 (69.79%)	10 (3, 30)

Bachelor's degree +	4762	594 (12.47%)	775 (16.27%)	3393 (71.25%)	8 (3, 29)
Unknown	68	11 (16.18%)	11 (16.18%)	46 (67.65%)	13 (4, 34)
Household Income					
0 <40k	5460	811 (14.85%)	892 (16.34%)	3757 (68.81%)	11 (3, 31)
40k-49k	1969	302 (15.34%)	325 (16.51%)	1342 (68.16%)	12 (3, 31)
50k-59k	2305	386 (16.75%)	408 (17.7%)	1511 (65.55%)	13 (4, 33)
60k-74k	3479	532 (15.29%)	587 (16.87%)	2360 (67.84%)	13 (4, 32)
75k-99k	5330	870 (16.32%)	893 (16.75%)	3567 (66.92%)	12 (4, 32)
100k+	8584	1076 (12.53%)	1200 (13.98%)	6308 (73.49%)	6 (3, 27)
Household Net Worth					
unknown	2632	265 (10.07%)	348 (13.22%)	2019 (76.71%)	6 (3, 23)
<25k	4893	564 (11.53%)	652 (13.33%)	3677 (75.15%)	6 (3, 24)
25k-149k	5429	747 (13.76%)	715 (13.17%)	3967 (73.07%)	7 (3, 27)
150k-249k	3211	466 (14.51%)	497 (15.48%)	2248 (70.01%)	10 (4, 30)
250k-499k	5370	848 (15.79%)	920 (17.13%)	3602 (67.08%)	12 (4, 32)
500k+	8256	1360 (16.47%)	1526 (18.48%)	5370 (65.04%)	14 (4, 33)
Clinical Characteristics					
No hypertension	3070	285 (9.28%)	342 (11.14%)	2443 (79.58%)	5 (3, 20)
Hypertension	26721	3965 (14.84%)	4316 (16.15%)	18440 (69.01%)	11 (4, 31)
No diabetes	17232	2330 (13.52%)	2531 (14.69%)	12371 (71.79%)	8 (3, 28)
Diabetes	12559	1920 (15.29%)	2127 (16.94%)	8512 (67.78%)	11 (4, 32)
No ischemic stroke/TIA	19044	2474 (12.99%)	2693 (14.14%)	13877 (72.87%)	7 (3, 27)
Ischemic Stroke/TIA	10747	1776 (16.53%)	1965 (18.28%)	7006 (65.19%)	14 (4, 33)
No myocardial infarction	14496	2164 (14.93%)	2452 (16.92%)	9880 (68.16%)	12 (4, 31)
Myocardial infarction	15295	2086 (13.64%)	2206 (14.42%)	11003 (71.94%)	8 (3, 28)

Initial Qualifying Event Type					
AMI with procedure	13414	1832 (13.66%)	1910 (14.24%)	9672 (72.1%)	7 (3, 28)
AMI without procedure	1881	254 (13.5%)	296 (15.74%)	1331 (70.76%)	11 (4, 29)
CABG	9672	1461 (15.11%)	1620 (16.75%)	6591 (68.15%)	11 (4, 31)
Heart Valve Procedure	13188	2016 (15.29%)	2238 (16.97%)	8934 (67.74%)	12 (4, 32)
PCI	13462	1815 (13.48%)	1885 (14%)	9762 (72.52%)	8 (3, 27)
Heart Transplant	131	18 (13.74%)	18 (13.74%)	95 (72.52%)	7 (3, 28)
Heart Transplant	131	18 (13.74%)	18 (13.74%)	95 (72.52%)	7 (3, 28)

[1] Adherence is calculated among those who initiated CR and were enrolled for ≥180 days after discharge

[2] (of those with enrollment >180 days)

Table 4. Odds of Participating in Cardiac Rehabilitation, by characteristic

Effect	Odds Ratio	95% Confidence Interval		p-value
Race				
Asian vs. White	0.55	0.50	0.61	p < 0.0001
Black vs. White	0.75	0.71	0.79	p < 0.0001
Hispanic vs. White	0.48	0.45	0.51	p < 0.0001
Sex				
Female vs. Male	0.93	0.90	0.96	p < 0.0001
Comorbidity				
Stroke/TIA	0.9	0.88	0.94	p < 0.0001
Hypertension	0.83	0.79	0.87	p < 0.0001
Diabetes	0.77	0.75	0.8	p < 0.0001
Income				
<$40K vs. >$100K	0.69	0.65	0.74	p < 0.0001
$50-59K vs. >$100K	0.73	0.69	0.78	p < 0.0001
$60-74K vs. >$100K	0.81	0.77	0.85	p < 0.0001
$75-99K vs. >$100K	0.93	0.89	0.98	p = 0.0038
Education				
<12th Grade vs. bachelor's degree	0.26	0.19	0.38	p < 0.0001
High School vs. bachelor's degree	0.65	0.61	0.68	p < 0.0001
Some College vs. bachelor's degree	0.89	0.85	0.93	p < 0.0001
Procedure Type				
CABG vs. AMI	12.50	11.11	12.55	p < 0.0001
PCTA/stent vs. AMI	4.35	4.00	4.55	p < 0.0001
Transplant vs. AMI	4.00	3.23	5.00	p < 0.0001
Valve Repair vs. AMI	5.00	4.76	5.26	p < 0.0001

adjusting for race, age, sex, Elixhauser score, HTN, diabetes, stroke, income, education, AND type of procedure (ref=AMI)

Appendix A

Appendix Table 1 ICD-9/ICD-10/CPT codes

	ICD-9	ICD-10	CPT
Myocardial Infarction	410.00, 410.01, 410.02, 410.10, 410.11, 410.12, 410.20, 410.21, 410.22, 410.30, 410.31, 410.32, 410.40, 410.41, 410.42, 410.50, 410.51, 410.52, 410.60, 410.61, 410.62, 410.70, 410.71, 410.72, 410.80, 410.81, 410.82, 410.90, 410.91, 410.92	I21.0, I21.01, I21.02, I21.09, I21.1, I21.11, I21.19, I21.2, I21.21, I21.29, I21.3, I21.4, I21.9, I21.A1†, I21.A9†, I22.0, I22.1, I22.2, I22.8, I22.9	
Coronary Artery Bypass Grafting	36.10, 36.11, 36.12, 36.13, 36.14, 36.15, 36.16, 36.17, 36.19, 36.2	0210X, 0211X, 0212X, 0213X	33510, 33511, 33512, 33513, 33514, 33516, 33517, 33518, 33519, 33521, 33522, 33523, 33530, 33533, 33534, 33535, 33536, 33572, 35600, S2205, S2206, S2207, S2208, S2209
Valve Repair/Replacement	35.00, 35.01, 35.02, 35.03, 35.04, 35.05, 35.06, 35.07, 35.08, 35.09, 35.10, 35.11, 35.12, 35.13, 35.14, 35.20, 35.21, 35.22, 35.23, 35.24, 35.25, 35.26, 35.27, 35.28, 35.33, 35.96, 35.97, 35.99	027F, 027G, 027H, 027J, 02CF, 02CG, 02CH, 02CJ, 02NF, 02NG, 02NH, 02NJ, 02QF, 02QG, 02QH, 02QJ, 02RF, 02RG, 02RH, 02RJ, 02ND, 02VG, 02UF, 02UG, 02UH, 02UJ, 06BQ, 5A12	33361-33417, 33418-33430, 33460-33468, 33470-33478

PCTA/stent	00.66, 36.03, 36.04, 36.06, 36.07, 36.09	02703ZZ, 02704ZZ, 02713ZZ, 02714ZZ, 02723ZZ, 02724ZZ, 02733ZZ, 02734ZZ, 3E07017, 3E070PZ, 3E07317, 3E073PZ, 02700ZZ, 02710ZZ, 02720ZZ, 02730ZZ, 02C00ZZ, 02C10ZZ, 02C20ZZ, 02C30ZZ, 02C03ZZ, 02C04ZZ, 02C13ZZ, 02C14ZZ, 02C23ZZ, 02C24ZZ, 02C33ZZ, 02C34ZZ,	92920, 92921, 92924, 92925, 92928, 92929, 92933, 92934, 92937, 92938, 92941, 92943, 92944, 92973, 92974
Heart Transplant	33.6, 37.51, 37.52, 37.53, 37.54,	0BYM0Z1, 0BYM0Z2, 02YA0Z0, 02YA0Z1, 02YA0Z2, 02RK0JZ, 02RL0JZ, 02WA0JZ, 02WA0JZ, 02YA0Z0, 02YA0Z1, 02YA0Z2, 0BYM0Z0	33945, 33927, 33928, 0051T, 0052T, 0053T
Chronic Stable Heart Failure	428.22, 428.42,	I50.22, I50.42, I50.82	
Stable Angina	413.0, 413.1, 413.9	I20.1, I20.8, I20.9	
Cardiac Rehabilitation			93798, 93797
Hypertension	401.X, 402.X, 404.X, 403.X, 405.X	I10.X, I11.X, I12.X, I13.X, I15.X	
Diabetes	250.X0, 250.X2	E11.X, 250.X1, 250.X3, E10.X	
Myocardial Infarction	410.X, 412.X	I21.X, I22.X, I23.X, I25.2	
Ischemic Stroke/TIA	433.X, 434.X, 436.X	I63.X, I65.X, I66.X, 435.X, G45.0, G45.1, G45.2, G45.8, G45.9, Z86.73, V12.54	

Appendix Table 2. Elixhauser comorbidity ICD10 codes

Elixhauser comorbidity ICD10 codes

Group	DX	Weight (AHQR)	Weight (van Walraven)	CORRESPONDING CODES
1	**CHF**	9	7	I09.9 I11.0 I13.0 I13.2 I25.5 I42.0 I42.5 I42.6 I42.7 I42.8 I42.9 I43.X I50.X P29.0
2	**Arrhythmias**	0	5	I44.1 I44.2 I44.3 I45.6 I45.9 I47.X I48.X I49.X R00.0 R00.1 R00.8 T82.1 Z45.0 Z95.0
3	**Valvular disease**	0	-1	A52.0 I05.X I06.X I07.X I08.X I09.1 I09.8 I34.X I35.X I36.X I37.X I38.X I39.X Q23.0 Q23.1 Q23.2 Q23.3 Z95.2 Z95.3 Z95.4
4	**Pulmonary circulation disorders**	6	4	I26.X I27.X I28.0 I28.8 I28.9
5	**Peripheral vascular disorders**	3	2	I70.X I71. I73.1 I73.8 I73.9 I77.1 I79.0 I79.2 K55.1 K55.8 K55.9 Z95.8 Z95.9
6	**Hypertension (uncomplicated)**	-1	0	I10.
7	**Hypertension (complicated)**	-1	0	I11.X I12.X II3.X I15.X
8	**Paralysis**	5	7	G04.1 G11.4 G80.1 G80.2 G81.X G82.X G83.0 G83.1 G83.2 G83.3 G84.4 G83.9
9	**Other neurological disorders**	5	6	G10.X G11.X G12.X G13.X G20.X G21.X G22.X G25.4 G25.5 G31.2 G31.8 G31.9 G32.X G35.X G36.X G37.X G40.X G41.X G93.1 G93.4 R47.0 R56.X
10	**Chronic pulmonary disease**	3	3	I27.8 I27.9 J40.x J41.X J42.X J43.X J44.X J45.X J46.X J47.X J60 J61 J62 J63 J64 J65 J66 J67 J68.4 J70.1 J70.3
11	**Diabetes (uncomplicated)**	0	0	E10.0 E10.1 E10.9 E11.0 E11.1 E11.9 E12.0 E12.1 E12.9 E13.0 E13.1 E13.9 E14.0 E14.1 E14.9
12	**Diabetes (complicated)**	-3	0	E10.2 E10.3 E10.4 E10.5 E10.6 E10.7 E10.8 E11.2 E11.3 E11.4 E11.5 E11.6 E11.7 E11.8 E12.2 E12.3 E12.4 E12.5 E12.6 E12.7 E12.8 E13.2 E13.3
				E13.4 E13.5 E13.6 E13.7 E13.8 E14.2 E14.3 E14.4 E14.5 E14.6 E14.7 E14.8
13	**Hypothyroidism**	0	0	E00.X E01.X E02.X E03.X E89.0
14	**Renal failure**	6	5	I12.0 I13.1 N18.X N19.X N25.0 Z49.0 Z49.1 Z49.2 Z94.0 Z99.2
15	**Liver disease**	4	11	B18.X I85.X I86.4 I98.2 K70.X K71.1 K71.3 K71.4 K71.5 K71.7 K72.X K73.X K74.4 K76.0 K76.2 K76.3 K76.4 K76.5 K76.6 K76.7 K76.8 K76.9 Z94.4
16	**Peptic ulcer disease (excluding bleeding)**	0	0	K25.7 K25.9 K26.7 K26.9 K27.7 K27.9 K28.7 K28.9
17	**AIDS/HIV**	0	g	B20.X B21.X B22.X B24.X
18	**Lymphoma**	6	9	C81. C82. C83. C84. C85. C88. C96. C90.0 C90.2
19	**Metastatic cancer**	14	12	C77. C78. C79. C80.
20	**Solid tumor w/o metastasis**	7	4	C00. C01. C02. C03. C04. C05. C06. C07. C08. C09. C10. C11. C12. C13. C14. C15. C16. C17. C18. C19. C20. C21. C22.
				C23. C24. C25. C26. C30. C31. C32. C33. C34. C37. C38. C39. C40. C41. C43. C45. C46. C47. C48. C49. C50. C51. C52.
				C53. C54. C55. C56. C57. C58. C60. C61. C62. C63. C64. C65. C66. C67. C68. C69. C70. C71. C72. C73. C74. C75. C76. C97.
21	**Rheumatoid arthritis/collagen vascular disease**	0	0	L94.0 L94.1 L94.3 M05.X M06.X M08.X M12.0 M12.3 M30.X M31.0 M31.1 M31.2 M31.3 M32. M33. M34. M35. M45. M46.1 M46.8 M46.9
22	**Coagulopathy**	11	3	D65. D66. D67. D68. D69.1 D69.3 D69.4 D69.5 D69.6
23	**Obesity**	-5	-4	E66.
24	**Weight loss**	9	6	E40. E41. E42. E43. E44. E45. E46. R63.4 R64.
25	**Fluid and electrolyte disorders**	11	5	E22.2 E86.x E87.x
26	**Blood loss anemia**	-3	-2	D50.0
27	**Deficiency anemia**	-2	-2	D50.8 D50.9 D51. D52. D53.
28	**Alcohol abuse**	-1	0	F10 E52 G62.1 I42.6 K29.2 K70.0 K70.3 K70.9 T51. Z50.2 Z71.4 Z72.1
29	**Drug abuse**	-7	-7	F11. F12. F13. F14. F15. F16. F18. F19. Z71.5 Z72.2
30	**Psychoses**	-5	0	F20. F22. F23. F24. F25. F28. F29. F30. F30.2 F31.2 F31.5
31	**Depression**	-5	3	F20.4 F31.3 F31.4 F31.5 F32. F33. F34.1 F41.2 F43.2

source: https://cran.r-project.org/web/packages/comorbidity/vignettes/comorbidityscores.html

source: Coding algorithms for defining comorbidities in ICD-9-CM and ICD-10 administrative data. Quan et al. Med Care 2005.

Appendix Table 3. Characteristics of those excluded due to missing race info vs included cohort

Characteristic	All included participants (n=121963)[1]	Participants excluded due to missing race (n=14204)
Cardiac Rehabilitation Qualifying Diagnosis		
Myocardial Infarction [3]	30615 (25.10%)	3408 (23.99%)
Coronary Artery Bypass Grafting	20978 (17.2%)	2622 (18.46%)
Valve Repair/Replacement	36549 (30.0%)	4490 (31.61%)
PCTA/stent	52130 (42.7%)	5982 (42.11%)
Heart Transplant	527 (0.4%)	58 (0.41%)
Sociodemographic Characteristics		
Age at admission, mean (SD)	70.0 (11.8)	70.9 (10.1)
Sex		
Female, n (%)	45951 (37.68%)	5334 (37.55%)
Male, n (%)	76004 (62.32%)	8863 (62.40%)
Unknown, n (%)	8 (0.01%)	7 (0.05%)
Race		
Asian, n (%)	3074 (2.52%)	
Black, n (%)	14732 (12.08%)	
Hispanic, n (%)	12530 (10.27%)	
White, n (%)	91627 (75.13%)	
Education Level		
<12th Grade, n (%)	680 (0.56%)	8 (0.24%)
High school diploma, n (%)	41677 (34.17%)	803 (23.9%)
< Bachelor's degree, n(%)	64950 (53.25%)	1944 (57.86%)
Bachelor's degree +, n (%)	14299 (11.72%)	588 (17.5%)
Unknown, n (%)	357 (0.29%)	17 (0.51%)
Household Income		
<40k, n (%)	33918 (31.51%)	667 (19.85%)
40k-49k, n (%)	9393 (8.73%)	199 (5.92%)
50k-59k, n (%)	10171 (9.45%)	219 (6.52%)
60k-74k, n (%)	13208 (12.27%)	345 (10.27%)
75k-99k, n (%)	17206 (15.98%)	510 (15.18%)

100k+, n (%)	23754 (22.07%)	824 (24.52%)
Household Net Worth		
unknown, n (%)	14136 (11.59%)	584 (17.38%)
<25k, n (%)	29975 (24.58%)	506 (15.06%)
25k-149k, n (%)	22584 (18.52%)	560 (16.67%)
150k-249k, n (%)	11660 (9.56%)	307 (9.14%)
250k-499k, n (%)	17995 (14.75%)	530 (15.77%)
500k+, n (%)	25613 (21%)	873 (25.98%)
Clinical Characteristics		
Hypertension, n (%)	112992 (92.64%)	13164 (92.68%)
Diabetes, n (%)	61517 (50.44%)	7051 (49.64%)
Ischemic stroke/TIA, n (%)	47154 (38.66%)	5263 (37.05%)
Myocardial Infarction, n (%)	73490 (60.26%)	8242 (58.03%)
Elixhauser, median (Q1, Q3)	16 (7, 25)	15 (6, 23)

Bibliography

Balady GJ, Williams MA, Ades PA, et al. Core Components of Cardiac Rehabilitation/Secondary Prevention Programs: 2007 Update. Circulation 2007;115(20):2675–82.

Smith SC, Benjamin EJ, Bonow RO, et al. AHA/ACCF Secondary Prevention and Risk Reduction Therapy for Patients With Coronary and Other Atherosclerotic Vascular Disease: 2011 Update. Circulation 2011;124(22):2458–73.

MEMBERS WC, Yancy CW, Jessup M, et al. 2013 ACCF/AHA Guideline for the Management of Heart Failure. Circulation 2013;128(16):e240–327.

Ades PA, Keteyian SJ, Wright JS, et al. Increasing Cardiac Rehabilitation Participation From20% to 70%: A Road Map From the Million Hearts Cardiac Rehabilitation Collaborative. Mayo Clin Proc 2017;92(2):234–42.

Suaya JA, Stason WB, Ades PA, Normand S-LT, Shepard DS. Cardiac Rehabilitation andSurvival in Older Coronary Patients. J Am Coll Cardiol 2009;54(1):25–33.

Eijsvogels TMH, Maessen MFH, Bakker EA, et al. Association of Cardiac RehabilitationWith All-Cause Mortality Among Patients With Cardiovascular Disease in the Netherlands.Jama Netw Open 2020;3(7):e2011686.

Goel K, Pack QR, Lahr B, et al. Cardiac rehabilitation is associated with reduced long-term mortality in patients undergoing combined heart valve and CABG surgery. Eur J Prev Cardiol2013;22(2):159–68.

Hammill BG, Curtis LH, Schulman KA, Whellan DJ. Relationship Between Cardiac Rehabilitation and Long-Term Risks of Death and Myocardial Infarction Among Elderly Medicare Beneficiaries. Circulation 2010;121(1):63–70.

Martin B-J, Hauer T, Arena R, et al. Cardiac Rehabilitation Attendance and Outcomes inCoronary Artery Disease Patients. Circulation 2012;126(6):677–87.

Dunlay SM, Pack QR, Thomas RJ, Killian JM, Roger VL. Participation in Cardiac Rehabilitation, Readmissions, and Death After Acute Myocardial Infarction. Am J Medicine 2014;127(6):538–46.

Lawler PR, Filion KB, Eisenberg MJ. Efficacy of exercise-based cardiac rehabilitation post–myocardial infarction: A systematic review and meta-analysis of randomized controlled trials. Am Heart J 2011;162(4):571-584.e2.

Choo CC, Chew PKH, Lai S-M, et al. Effect of Cardiac Rehabilitation on Quality of Life, Depression and Anxiety in Asian Patients. Int J Environ Res Pu 2018;15(6):1095.

Milani RV, Lavie CJ. Impact of Cardiac Rehabilitation on Depression and Its AssociatedMortality. Am J Medicine 2007;120(9):799–806.

Taylor RS, Walker S, Smart NA, et al. Impact of Exercise Rehabilitation on Exercise Capacity and Quality-of-Life in Heart Failure Individual Participant Meta-Analysis. J Am CollCardiol 2019;73(12):1430–43.

Kasperowicz A, Cymerys M, Kasperowicz T. Effectiveness of Cardiac Rehabilitation in Exercise Capacity Increase in Patients with ST-Segment Elevation Myocardial Infarction. Int J Environ Res Pu 2019;16(21):4085.

Golwala H, Pandey A, Ju C, et al. Temporal Trends and Factors Associated With Cardiac Rehabilitation Referral Among Patients Hospitalized With Heart Failure Findings From Get With The Guidelines–Heart Failure Registry. J Am Coll Cardiol 2015;66(8):917–26.

Li S, Fonarow GC, Mukamal K, et al. Sex and Racial Disparities in Cardiac Rehabilitation Referral at Hospital Discharge and Gaps in Long-Term Mortality. J Am Heart Assoc 2018;7(8).

Aragam KG, Dai D, Neely ML, et al. Gaps in Referral to Cardiac Rehabilitation of Patients Undergoing Percutaneous Coronary Intervention in the United States. J Am Coll Cardiol 2015;65(19):2079–88.

Brown TM, Hernandez AF, Bittner V, et al. Predictors of Cardiac Rehabilitation Referral in Coronary Artery Disease Patients Findings From the American Heart Association's Get With The Guidelines Program. J Am Coll Cardiol 2009;54(6):515–21.

Beatty AL, Truong M, Schopfer DW, Shen H, Bachmann JM, Whooley MA. Geographic Variation in Cardiac Rehabilitation Participation in Medicare and Veterans Affairs Populations. Circulation 2018;137(18):1899–908.

Suaya JA, Shepard DS, Normand S-LT, Ades PA, Prottas J, Stason WB. Use of Cardiac Rehabilitation by Medicare Beneficiaries After Myocardial Infarction or Coronary Bypass Surgery. Circulation 2007;116(15):1653–62.

Goel K, Lennon RJ, Tilbury RT, Squires RW, Thomas RJ. Impact of Cardiac Rehabilitationon Mortality and Cardiovascular Events After Percutaneous Coronary Intervention in the Community. Circulation 2011;123(21):2344–52.

Patel DK, Duncan MS, Shah AS, et al. Association of Cardiac Rehabilitation With Decreased Hospitalization and Mortality Risk After Cardiac Valve Surgery. Jama Cardiol 2019;4(12):1250–9.

Zullo MD, Gathright EC, Dolansky MA, Josephson RA, Cheruvu VK, Hughes JW. Influenceof Depression on Utilization of Cardiac Rehabilitation Postmyocardial Infarction. J Cardiopulm Rehabil 2017;37(1):22–9.

Ritchey MD, Maresh S, McNeely J, et al. Tracking Cardiac Rehabilitation Participation and Completion Among Medicare Beneficiaries to Inform the Efforts of a National Initiative. Circulation Cardiovasc Qual Outcomes 2020;13(1):e005902.

Prince DZ, Sobolev M, Gao J, Taub CC. Racial Disparities in Cardiac RehabilitationInitiation and the Effect on Survival. Pm&r 2014;6(6):486–92.

Colella TJ, Gravely S, Marzolini S, et al. Sex bias in referral of women to outpatient cardiac rehabilitation? A meta-analysis. Eur J Prev Cardiol 2013;22(4):423–41.

Samayoa L, Grace SL, Gravely S, Scott LB, Marzolini S, Colella TJF. Sex Differences inCardiac Rehabilitation Enrollment: A Meta-analysis. Can J Cardiol 2014;30(7):793–800.

Balady GJ, Ades PA, Bittner VA, et al. Referral, Enrollment, and Delivery of Cardiac Rehabilitation/Secondary Prevention Programs at Clinical Centers and Beyond. Circulation 2011;124(25):2951–60.

Shanmugasegaram S, Oh P, Reid RD, McCumber T, Grace SL. Cardiac rehabilitationbarriers by rurality and socioeconomic status: a cross-sectional study. Int J Equity Health 2013;12(1):72.

Allen JK, Scott LB, Stewart KJ, Young DR. Disparities in Women's Referral to andEnrollment in Outpatient Cardiac Rehabilitation. J Gen Intern Med 2004;19(7):747–53.

Armstrong MJ, Sigal RJ, Arena R, et al. Cardiac rehabilitation completion is associated with reduced mortality in patients with diabetes and coronary artery disease. Diabetologia 2015;58(4):691–8.

Dunlay SM, Witt BJ, Allison TG, et al. Barriers to participation in cardiac rehabilitation. AmHeart J 2009;158(5):852–9.

Edwards K, Jones N, Newton J, et al. The cost-effectiveness of exercise-based cardiac rehabilitation: a systematic review of the characteristics and methodological quality of publishedliterature. Heal Econ Rev 2017;7(1):37.

Bennett KK, Smith AJ, Harry KM, et al. Multilevel Factors Predicting Cardiac Rehabilitation Attendance and Adherence in Underserved Patients at a Safety-Net Hospital. J Cardiopulm Rehabil 2019;39(2):97–104.

Bachmann JM, Huang S, Gupta DK, et al. Association of Neighborhood SocioeconomicContext With Participation in Cardiac Rehabilitation. J Am Heart Assoc 2017;6(10).

Mazzini MJ, Stevens GR, Whalen D, Ozonoff A, Balady GJ. Effect of an American Heart Association Get With the Guidelines Program-Based Clinical Pathway on Referral and Enrollment Into Cardiac Rehabilitation After Acute Myocardial Infarction. Am J Cardiol 2008;101(8):1084–7.

Frieden TR, Berwick DM. The "Million Hearts" Initiative — Preventing Heart Attacks andStrokes. New Engl J Medicine 2011;365(13):e27.

Drwal KR, Forman DE, Wakefield BJ, Accaoui RNE. Cardiac Rehabilitation During COVID-19 Pandemic: Highlighting the Value of Home-Based Programs. Telemed E-health 2020;26(11):1322–4.

Snoek JA, Prescott EI, Velde AE van der, et al. Effectiveness of Home-Based Mobile Guided Cardiac Rehabilitation as Alternative Strategy for Nonparticipation in Clinic-Based Cardiac Rehabilitation Among Elderly Patients in Europe. Jama Cardiol 2021;6(4).

Schopfer DW, Whooley MA, Allsup K, et al. Effects of Home-Based Cardiac Rehabilitationon Time to Enrollment and Functional Status in Patients With Ischemic Heart Disease. J Am Heart Assoc 2020;9(19):e016456.

Thomas RJ, Beatty AL, Beckie TM, et al. Home-Based Cardiac Rehabilitation: A Scientific Statement From the American Association of Cardiovascular and Pulmonary Rehabilitation, theAmerican Heart Association, and the American College of Cardiology. Circulation 2019;140(1):e69–89.

DeFrank JT, Bowling JM, Rimer BK, et al. . Triangulating differential nonresponse by racein a telephone survey. Prev Chronic Dis 2007;4:A60.

Quan H, Sundararajan V, Halfon P, et al. Coding algorithms for defining comorbidities inICD-9-CM and ICD-10 administrative data. Med Care. 2005;43(11):1130–9.

Elixhauser A, Steiner C, Harris DR, Coffey RM. Comorbidity measures for use withadministrative data. Med Care. 1998;36