Cardiovascular Health in Young and Middle Adulthood and Medical Care Utilization and Costs at Older Age – The Chicago Heart Association Detection Project Industry (CHA)

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Abstract

It is unclear how long-term medical utilization and costs from diverse care settings and their age-related patterns may differ by cardiovascular health (CVH) status earlier in adulthood. We followed 17,195 participants of the Chicago Heart Association Detection Project Industry (1967–1973) with linked Medicare claims (1992 to 2010). Baseline CVH is a composite measure of blood pressure, body mass index, diabetes, cholesterol, and smoking and includes four mutually exclusive strata: all factors were favorable (5.5%), one or more factors were elevated but none high (20.3%), one factor was high (40.9%), and two or more factors were high (33.2%). We assessed

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differences in the quantities (using negative binomial models) of and costs (using quantile regressions) for inpatient admissions, ambulatory care, home health care, and others between less favorable and all favorable CVH. All analyses adjusted for baseline age, race, sex, education, age at follow-up, year, state of residence, and death. We found that all favorable CVH in earlier adulthood was associated with lower long-term utilization and costs in all settings and the gap widened with age. Compared to all favorable CVH, the annual number of acute inpatient admissions per person was 79% greater (p-value < 0.001) for poor CVH, the median annual Medicare payment per person was $640 greater (41%, p-value < 0.001), and the mean was $4,628 greater (67%, p-value < 0.001). The cost differences were greatest for acute inpatient, followed by ambulatory, post-acute inpatient, home health, and other. Early prevention efforts may potentially result in compressed all-cause morbidity in later years of age, along with reductions in resource use and health care costs for associated conditions.

Keywords

cardiovascular health; healthcare utilization; healthcare costs

Introduction

U.S. healthcare spending is projected to grow from 17.8% of national gross domestic product (GDP) in 2015 to 20.1% of national GDP by 2025.[1,2] Although the rise in healthcare spending is attributable to myriad factors, growing Medicare costs due to an aging population with a greater incidence of chronic diseases could likely further increase spending.[3,4,5,6] According to a recent report published by the American Heart Association, by 2035 approximately 45% (131.2 million) of the U.S. adult population will have some form of cardiovascular diseases (CVD), up from 41.5% (102.7 million) in 2015 and CVD-related medical costs will more than double during this period.[7]

Past research indicates that better cardiovascular health (CVH) is associated with compressed all-cause morbidity and lower medical care costs at later ages.[8–19] However, the evidence to date is mostly limited by short follow-ups or small cohorts and a particular focus on overall medical care costs, failing to distinguish the distribution of costs across health resources. Specifically, it is unclear how long-term medical utilization and costs from diverse care settings (e.g., acute inpatient and home health care) and their age-related patterns may differ by baseline CVH status. Answers to these questions provide a unique lens to understand how and where favorable CVH earlier in life may be resulting in reduced costs in later ages.

Using linked, complete Medicare Part A and Part B claims from 1992 to 2010 for participants of the Chicago Heart Association Detection Project Industry (CHA, 1967 – 1973), we examined the associations between their baseline cardiovascular health (CVH) status and annual medical utilization and costs from various care settings at older ages. The study is novel given its long follow-up period (up to 40 years) and the fact that it uses all Part A and Part B claims. Specifically, we examined total costs and the quantities of and costs for acute inpatient admissions, post-acute inpatient admissions, ambulatory care visits,

home health visits, and others. The answers to these questions will provide unique evidence on the later-life healthcare experiences of individuals with various CVH status earlier in adulthood and generate policy implications regarding to the potential health and financial benefits of investments in health early in life.

Methods

Sample

The CHA Study assessed cardiovascular health for 39,665 participants (baseline aged between 18 and 77 years) between 1967 and 1972.[15] The study collected information on participants' demographic characteristics at baseline including age, sex, race, education, and biometrics data including height, weight, systolic blood pressure, diastolic blood pressure, serum cholesterol (total cholesterol), serum uric acid, 1-hour plasma glucose, cigarette smoking, diabetes, and medical history such as history of diagnosed high blood pressure, high cholesterol, and hyperuricemia.

Among the CHA participants (see Appendix A for the diagram for sample selection), we excluded those whose baseline CVH measures were missing (n=4,432). To focus on participants who were age-eligible for Medicare during follow-up (and therefore likely enrolled in Medicare) between 1992 and 2010 (when linked data were available), we excluded those who died before age 65 (n=3,179), were younger than 65 years in 2010 (n=5,310), or died before 1992 (n=2,737). These exclusions resulted in 24,007 age-eligible participants between 1992 and 2010. Of them, 20,326 participants were successfully matched to the Administrative Medicare enrollment file by SSN, year of birth, and sex. We then included only participants who had both Medicare Part A and Part B benefits for the full year (number excluded =1,841). Claims for managed care beneficiaries were not available, therefore, we excluded individuals who were enrolled in managed care for any month during a year (n=1,076). Finally, we excluded individuals who were younger than 66 years because they may have only partial-year Medicare coverage (n=214). This study has been continuously approved by the Institutional Review Board and has a waiver of consent.

Our final longitudinal analysis sample included 17,195 unique CHA participants aged between 22 and 76 years (mean age =43) at baseline followed for 158,306 person-years during Medicare eligibility (i.e., after age 66 years). The unit of observation is person-year. On average, a participant was followed in Medicare for 9.2 years.

Baseline Cardiovascular Health (CVH)

Baseline CVH risk factors measured in the CHA study in 1967–1972 included blood pressure, body mass index (BMI), diabetes, total cholesterol, and cigarette smoking. As in prior studies,[11] we divided the sample into four mutually exclusive CVH strata: all factors were favorable (hereafter, all favorable), one or more factors were elevated but none was high (hereafter, 1+ elevated, none high), one factor was high (thereafter, 1 high), and two or more factors were high (thereafter, 2+ high). Table 1 provides details on the definitions of favorable, elevated, and high levels of CVH factors, which reflect standard clinical practice

guidelines and have been used in prior publications.[11] Table 2 provides the percent distribution of each of the five risk factors for each CVH stratum.

Medical Care Utilization and Costs

Medical care utilization and costs were ascertained from linked Medicare Part A and Part B claims from 1992 to 2010. These claims files included Medicare Provider Analysis and Review (inpatient and skilled nursing facilities), outpatient (hospital outpatient), carrier (physician/supplier Part B claims), durable medical equipment (DME), home health agency, and hospice files.

We calculated the medical care utilization and costs for each beneficiary by year (therefore by age). Medical care utilization included the number and total length (in days) of acute inpatient admissions, the number and total length of post-acute inpatient admissions, the number of ambulatory care visits, and the number of home health visits. Acute and post-acute inpatient cost/services were defined using the algorithms recommended in the Chronic Condition Data Warehouse (CCW) Technical Guidance for using CMS Medicare Administrative Research Files (July 2016, Version 2.3) published by CMS. Specifically, post-acute inpatient admissions included admissions to long-term care hospitals (the 3rd and 4th digits of the provider number are 20, 21, or 22), inpatient rehabilitation facilities (the last 4 digits of the provider number are between 3025 and 3099 or the 3rd digit being R or T), and skilled nursing facilities (the SNF indicator). Acute inpatient admissions include admissions to inpatient prospective payment system reimbursed hospitals (the 3rd digit of provider number is zero), critical access hospitals (3rd and 4th digits equal to 13), and other hospitals not counted as post-acute care hospitals.[20] Ambulatory care visits include visits to physician offices and clinics, hospital outpatient departments, emergency rooms without inpatient admission, and other non-institutional ambulatory care providers. Because claims for ambulatory care are located in both the outpatient and carrier files, we combined the two files and defined a visit by beneficiary ID, and claim from and through date to avoid double counting a visit with multiple claims.

We also analyzed these utilization categories according to the primary reason for admission or visit, defined as a cardiovascular disease (CVD) or non-cardiovascular disease (non-CVD). CVD visits and admissions were identified using primary diagnosis codes (ICD-9-CM) and included ischemic heart diseases, heart failure, peripheral vascular diseases, and stroke (ICD-9 codes included 410 through 414, 402.01, 402.11, 402.91, 429.3, 425, 428, 440, 4412, 441.4, 441.7, 441.9, 443.1 through 443.9, 447.1, 557.1, 557.9, v434, 434, and 436).[21]

We then examined differences in medical care costs for those with less favorable CVH at baseline compared to those with all favorable CVH. Because charges can vary across care facilities for reasons unrelated to patients' medical conditions,[22–24] we measured costs using Medicare payment amount, which was the amount Medicare paid for covered services and therefore a good representation of the financial burden to the Medicare program. In a small number of cases where the Medicare payment amount was negative because a beneficiary's deductible or coinsurance amount exceeded the amount Medicare paid, we set the Medicare payment amount to zero.[25] This was required in only 0.03% of all inpatient claims, 0.1% of

all outpatient and carrier claims, and there were no changes for DME, home health, and hospice claims. We excluded denied claims before calculating utilization and costs. All costs were adjusted to 2016 dollars using the medical care services component of the consumer price indexes published by the U.S. Bureau of Labor Statistics.

We calculated total costs as total Medicare payment amount incurred in all care settings for each individual by year. To calculate costs by types of care, we divided the total costs into mutually exclusive categories, including costs for acute inpatient admissions, post-acute inpatient admissions, ambulatory care visits, home health care visits, and others. All costs vary by person and year. Acute inpatient costs is the total amount that Medicare paid hospitals and physicians for acute inpatient services; post-acute inpatient costs is the total amount that Medicare paid facilities and physicians for post-acute inpatient services; ambulatory care costs is the total amount Medicare paid for ambulatory care; home health costs is the total amount Medicare paid for home health visits; and other costs include costs incurred in hospice care and retail DME.[20] Similar to utilization, we also categorized costs related to CVD and costs related to non-CVD.

Statistical Analysis

Sample characteristics were summarized by CVH strata and included average age at follow-up and at baseline, percent female, white, black, with a high school degree, and with a more than high school degree. We also calculated the mean and median of medical utilization and costs for each stratum. F test was used to compare differences across CVH stratum. To assess the age pattern in medical costs, we calculated average costs by age for each stratum and plotted them using a local polynomial smoothing method.

We used a multivariate regression model where an individual's medical care utilization (or costs) is a function of baseline CVH, age at follow-up (entered as linear and quadratic terms), year effects, state of residence effects, and other covariates including baseline age, race, sex, education, and an indicator for whether an individual died during the year. We entered baseline CVH as three dummy variables representing the three less favorable CVH strata: 1+ elevated, none high; 1 high; and 2+ high, using all favorable as the reference stratum.

We controlled for the year effect to account for aggregate temporal differences (such as new medical technology/treatment) that could lead to differences in utilization and costs across periods and, in particular, across birth cohorts at the same age. We also controlled for state effects to account for potential geographic differences in healthcare utilization and costs because the Medicare enrollment files show that over time CHA participants have moved to diverse regions of the country and because both medical care utilization and reimbursement vary by locality.[26–28] We found that because baseline CVH only weakly correlated with later state of residence, the inclusion of state effects had little impact on the estimates. Finally, because end-of-life health costs may follow a different pattern from average annual costs for an individual,[29] we included an indicator for whether a person died during the year. In sensitivity analyses we stratified by whether an individual died in sample to confirm that findings were consistent.

We used a negative binomial model to examine differences in utilization between less favorable CVH and all favorable CVH. Negative binomial models are commonly used in modeling count data (e.g. number of admissions/visit) and have less restrictive assumptions than do Poisson models.[30] Marginal effects associated with less favorable CVH were calculated at the mean of covariates. We used cluster-robust standard errors clustered by individual to account for within individual correlation in healthcare utilization across periods.[30] These standard errors are larger than the Huber-White standard errors which suggests that our estimates of statistical significance are conservative. In order to assess age patterns in the differences in utilization, marginal effects were calculated for each age with all other covariates fixed at their mean. We conducted the analyses on the full sample and also stratified by sex.

We used quantile regressions to examine differences in costs between poor CVH and all favorable CVH. Quantile regression methods estimate the conditional quantile functions instead of conditional mean functions and are therefore less likely to be influenced by outliers than conditional mean comparisons.[30,31] An additional advantage of quantile regressions is that it allows us to examine cost differences at different points of the cost distribution.[30] To examine whether the differences in cost vary across the cost distribution, we estimated quantile regressions at various percentiles of the costs: the 25th percentile, 50th percentile, 75th percentile, 90th percentile, and 95th percentile where applicable due to the highly skewed nature of the cost data and the mass of true zeros. We also supplemented the quantile estimates with GLM estimates which represent mean differences in costs conditional on covariates. We used a gamma distribution and a log-link function which provided the best fit to the cost data compared with alternative distributions. Combined, quantile regressions and GLM provide a fuller understanding of the cost differences than either approach alone. Again, we used cluster-robust standard errors at the individual level to adjust for intra-individual correlation of healthcare costs across periods.[30] We performed the analyses on the full sample and also stratified by sex. All statistical analyses were performed using Stata statistical software (version 14, StataCorp, TX).

Results

Sample Characteristics and Summary Statistics

Among the 17,195 CHA participants, 5.5% (951) had all favorable CVH, 20.3% (3,496) had one or more risk factors elevated but none high, 40.9% (7,040) had 1 risk factor high, and 33.2% (5,708) had 2+ high risk factors at baseline (Table 3). Table 2 shows the percent distribution of each risk factor by CVH strata. For example, nearly 33% of the participants in the 2+ high group were obese and 62% were current smokers, compared to 5% and 38% respectively in the 1 High group. On average, less favorable CVH strata were slightly older, had fewer women, and had lower educational attainment than the all favorable stratum. Overall, medical care utilization and costs (unadjusted) were substantially lower for individuals with all favorable CVH than those with less favorable CVH across all care settings (Table 3). In addition, the average costs by age (unadjusted) were generally lower for individuals with all favorable CVH for all types of care (Figure 1). Across the cost

distribution for each type of care, costs at various percentiles were also generally lower for individuals with all favorable CVH (Supplemental Figure 1).

Medical Care Utilization: Estimates from Negative Binomial Regressions

After adjusting for differences in observed characteristics, individuals with less favorable baseline CVH used significantly more medical care services later in life than individuals with favorable CVH; and the poorer the baseline CVH, the greater the utilization (Table 4). For example, while approximately 19% of the all favorable stratum had acute inpatient admissions per year, roughly 34% of the 2+ high risk stratum did (79% greater, p-value < 0.001). Additionally, the number of home health visits per person per year for the 2+ high risk stratum was 1.76 (125%, p-value < 0.001) greater than that of the all favorable stratum. We observed few significant differences in the association by sex (Panel B of Table 4). Across all categories examined, the gaps in medical care utilization between individuals with less favorable CVH and those with all favorable CVH widened with age (Figure 2).

Additionally, both CVD and non-CVD related utilizations were substantially higher for individuals in less favorable baseline CVH (Supplemental Table 1). For example, compared to the all favorable stratum, the number of CVD related acute inpatient admissions per person per year was 0.05 greater (250%, p-value < 0.001) for the 2+ high risk stratum, and the number of non-CVD related admissions was 0.10 (59%, p-value < 0.001) greater. While the absolute differences were greater for non-CVD related utilization, the relative (%) differences were greater for CVD related utilizations.

Medical Care Costs: Estimates from Quantile Regressions and GLM

Across all quantiles, less favorable CVH was associated with higher costs including total costs and costs by primary reason for care and care setting (Table 5). For example, compared to the all favorable stratum, the median of annual Medicare payment amount per person was $640 higher (p-value < 0.001) for the 2+ high risk stratum (41% higher than the median annual costs of $1,548 for the all favorable group) and the mean of annual Medicare payment amount per person was $4,628 (67%, p-value < 0.001) higher. The cost differences (in dollars) per person per year between less favorable CVH strata and all favorable stratum were greatest for acute inpatient care, followed (in descending order) by ambulatory care, post-acute inpatient care, home health care, and other care (hospice and durable medical equipment).

There were some statistically significant sex differences in the association between CVH and CVD related costs (Supplemental Table 2 and Supplemental Table 3). Specifically, the cost differences at the 75th, 90th, and 95th percentile between 2+ High and all favorable and between 1 High and all favorable were smaller for women than men. However, the differences in mean costs were statistically indistinguishable.

Consistent with greater absolute differences in non-CVD related utilization (Supplemental Table 1), the cost differences (in dollars) associated with less favorable CVH were greater for non-CVD related costs (Table 5). For example, compared to the all favorable stratum, the 90th percentile costs for the 2+ high stratum was $8,239 greater (p-value < 0.001) per person

per year for non-CVD related cost, compared to $1,058 greater (p-value < 0.001) for CVD related cost.

Sensitivity Analysis

Our estimates of utilization and cost differences between less favorable CVH and all favorable CVH represent annual differences per person. Among the 17,195 participants, approximately 49% had died by year 2010, including 26% of the all favorable stratum, 38% of the 1+ elevated, none high stratum, 48% of the 1 high stratum, and 61% of the 2+ high stratum. Because greater cardiovascular risk burden earlier in life is associated with shorter life expectancy,[15,32] and to gauge how the end of life care may affect our results, we conducted stratified analyses on those were still alive in 2010 (hereafter, survivors) and those who died in sample by 2010 (hereafter, decedents). Compared to the stratified estimates (Supplemental Table 4a and 4b), our main estimates on utilization and costs (Table 4 and Table 5) are closer to those from the decedent sample than from the survivor sample.

Additionally, those with less favorable CVH were followed slightly longer, specifically, the average length of follow-up was 8.65 years, 9.99 years, 9.23 years, and 8.79 years for those with favorable CVH, with 1+ Elevated, None High, with 1 High, and with 2+ High (p-value < 0.001). However, our results are robust (almost identical) when the length of follow-up in Medicare was included as an additional regressor, suggesting that our results were not driven by the differences in the lengths of follow-up between the CVH groups (Supplemental Table 5).

Discussion

In this paper, we used a composite measure of cardiovascular health earlier in adulthood that incorporated major risk factors including blood pressure, total cholesterol, diabetes, BMI, and smoking and assessed its association with medical care utilization and costs at older ages, up to 40 years later. We found that favorable cardiovascular health in young and middle adulthood was associated with significantly lower medical care utilization and costs at older ages (66 years and older) across all care settings.

Individuals with all favorable baseline CVH had approximately half as many acute inpatient admissions (which were also half the length), post-acute inpatient admissions, home health care visits, and three fewer ambulatory care visits per person per year than those with poor baseline CVH at older ages. Moreover, the differences in utilization persist through life and become more pronounced with age. These findings suggest that individuals with favorable CVH earlier in adulthood had lower morbidity burden by age at old ages, indicating compressed morbidity.[11] Consistent with patterns of utilization, individuals with favorable baseline CVH had significantly lower costs across all settings. The median amount that Medicare paid for medical care per person per year was $640 smaller for individuals with all favorable CVH and the mean amount was $4,628 smaller. Because we used the amount Medicare paid for medical care goods and services as our measure of costs, our costs do not include patient cost-sharing and, therefore, our cost estimates may understate the actual cost-savings associated with favorable CVH.

Past research indicates that better cardiovascular health (CVH) is associated with lower risks of diseases and medical care costs at later ages.[8–19] Other studies of the CHA cohort, all but one with shorter follow-ups, found that favorable CVH in middle age was associated with lower all-cause morbidity and lower medical costs later in life.[11–15] Studies of other cohorts, albeit with smaller cohorts or shorter follow-ups, found that better CVH was associated with lower CVD risks and lower CVD and non-CVD costs.[16, 18] Additionally, cross-sectional comparisons of individuals with different CVH status also suggest that favorable CVH was associated with lower healthcare expenditures and utilization.[17,19]

Additional to the longer follow-up (up to 40 years), to our knowledge this study is the first to dissect the overall healthcare utilization and costs by all settings of care. Because we used all Medicare Part A and Part B claims for fee-for-service Medicare enrollees, our estimates represent closely the full resource and cost savings. This approach provides a unique lens to understand how and where favorable CVH earlier in life may be resulting in reduced costs in the long term. Importantly, our results suggest that investing in health early in life may have substantial health and financial benefits later in life.

This study has several limitations. One limitation of this study is that we cannot assess changes in CVH status between baseline and Medicare claims. However, prior studies have found baseline CVH to be strongly predictive of later life CVH status.[11,14,32,33] Moreover, using Medicare claims we examined the prevalence of hypertension (ICD-9 codes: 401), diabetes (ICD-9 codes: 250), obesity (ICD-9 codes: 278), and hyperlipidemia (ICD-9 codes: 272.4) which corresponded to the CVH risk factors assessed as baseline. The results (Supplemental Table 6) show that participants with less favorable baseline CVH continued to have poorer CVH at baseline than those with more favorable CVH (p-value <0.01). If, however, individuals with less favorable CVH at baseline were more likely to improve their subsequent health behaviors than individuals with favorable CVH, then our estimates would likely be an underestimate and therefore conservative. An additional limitation is that there were no data on diet, physical activity, or family history of CVD. Information on subsequent lifestyle factors (e.g., diet and physical activity), various medical care after baseline, and family history of CVD would provide valuable insights into these factors' potential mediating roles between baseline CVH and later-life health care costs and would generate relevant policy implications. To this end, our results reflect the average differences in later-life medical care utilization and costs associated with baseline CVH. While we are unable to separately estimate the mediating impact of subsequent lifestyle factors and medical care, our estimates suggest that baseline CVH remain a strong predictor of medical care utilization and costs up to 40 years later and are therefore policy relevant.

If individuals with less favorable baseline CVH were to receive more medical care and more likely to adjust lifestyle factors following the baseline (because they were sicker), then our results may be an underestimate and therefore conservative. If individuals with more favorable CVH were to receive more medical care and more likely to adjust lifestyle factors following the baseline, then our estimates may be an overestimate. However, the second situation seems less likely especially because we also controlled for education (which is also a good proxy for income) – comparisons are made between individuals with the same levels of education.

A third limitation is that claims data were not available for managed care enrollees. If individuals with different baseline CVH non-randomly switched between fee-for-service (FFS) and managed care between periods, the estimates may potentially be biased. To assess such a possibility, we included in the model three additional covariates that measure potential shifts in sample composition by CVH strata and year: fraction switched from FFS to managed care, fraction switched from managed care to FFS, and fraction stayed in managed care. The inclusion of these additional covariates had limited impact on our estimates (Supplemental Table 7). Additionally, the estimates on costs by care setting and primary reason for admission/visit are also close to the main estimates shown in Table 4 and 5. Therefore, this does not seem to have affected our results.

Additionally, our analysis sample did not include CHA participants who died before the age 65 due to the lack of Medicare claims data. Using CMS Vital Status File (2012), we found that 4.9% of CHA participants with all favorable CVH died before the age 65, while 4.7% of the 1+ elevated, none high group, 8.3% of the 1 high group, and 13.1% of the 2+ high group died before the age 65. This evidence may suggest potential selective mortality, which if true, would suggest that our results excluding these individuals may be conservative (biased downward). A fifth limitation is the lack of Medicare Part D drug claims, which, however, were not available before 2006 – the year when Part D was implemented. As a result, our measure of total costs does not include the costs for prescription drugs filled under Medicare Part D benefits. Assume that the medication usage follows a similar pattern with other medical utilizations we examined in the paper, the differences in total costs and therefore cost-savings associated with favorable CVH are likely underestimated. Finally, our results may not generalize to populations with different demographic characteristics from the CHA sample, for example, the CHA sample is predominantly White. Due to the small sample sizes for non-White races, we are unable to identify whether there is heterogeneity in the association between baseline CVH and later-life costs by race.

Our findings are relevant to policy makers, public health, and the general audience. Up to 40 years later, cardiovascular health status in young and middle adulthood remains a strong predictor of medical care utilization and costs (therefore, overall health). Favorable CVH in young and middle adulthood was associated with significantly lower Medicare spending during Medicare eligibility, raising the possibility that primordial and primary prevention of cardiovascular risks may provide substantial savings to Medicare and taxpayers in the long term. In fact, many of the major cardiovascular risk factors are modifiable and preventable through changes in life style such as diet, physical activity and use of cost effective lipid or blood pressure lowering medication.[34–37] Although cost analysis of early prevention efforts is not the focus of this study, our estimates suggest potentially substantial long-term benefits from having a favorable CVH at young and middle age.
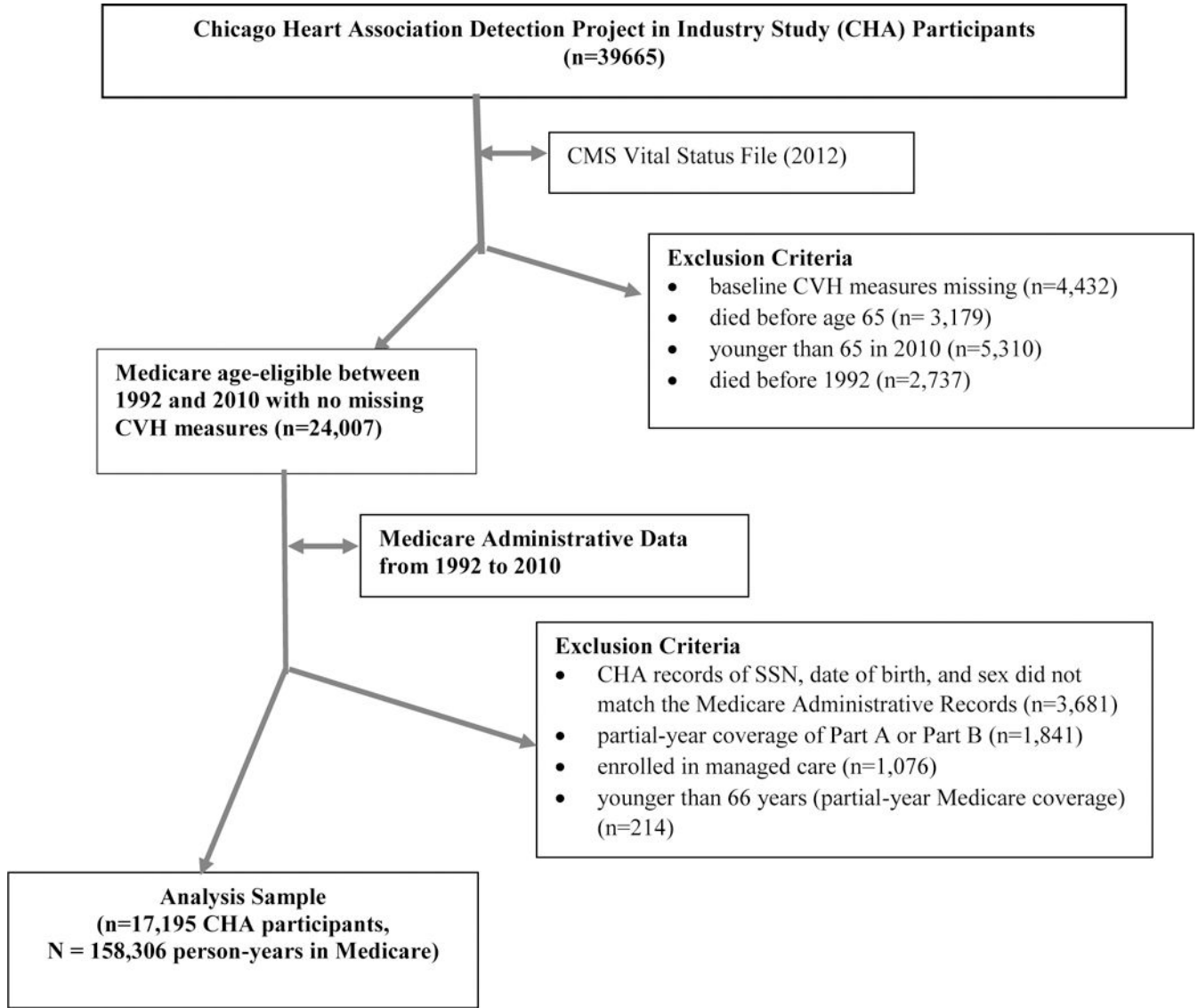
Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Appendix A.: Diagram for Sample Selection

Chicago Heart Association Detection Project in Industry Study (CHA) Participants
(n=39665)

CMS Vital Status File (2012)

Exclusion Criteria
- baseline CVH measures missing (n=4,432)
- died before age 65 (n= 3,179)
- younger than 65 in 2010 (n=5,310)
- died before 1992 (n=2,737)

Medicare age-eligible between 1992 and 2010 with no missing CVH measures (n=24,007)

Medicare Administrative Data from 1992 to 2010

Exclusion Criteria
- CHA records of SSN, date of birth, and sex did not match the Medicare Administrative Records (n=3,681)
- partial-year coverage of Part A or Part B (n=1,841)
- enrolled in managed care (n=1,076)
- younger than 66 years (partial-year Medicare coverage) (n=214)

Analysis Sample
(n=17,195 CHA participants,
N = 158,306 person-years in Medicare)

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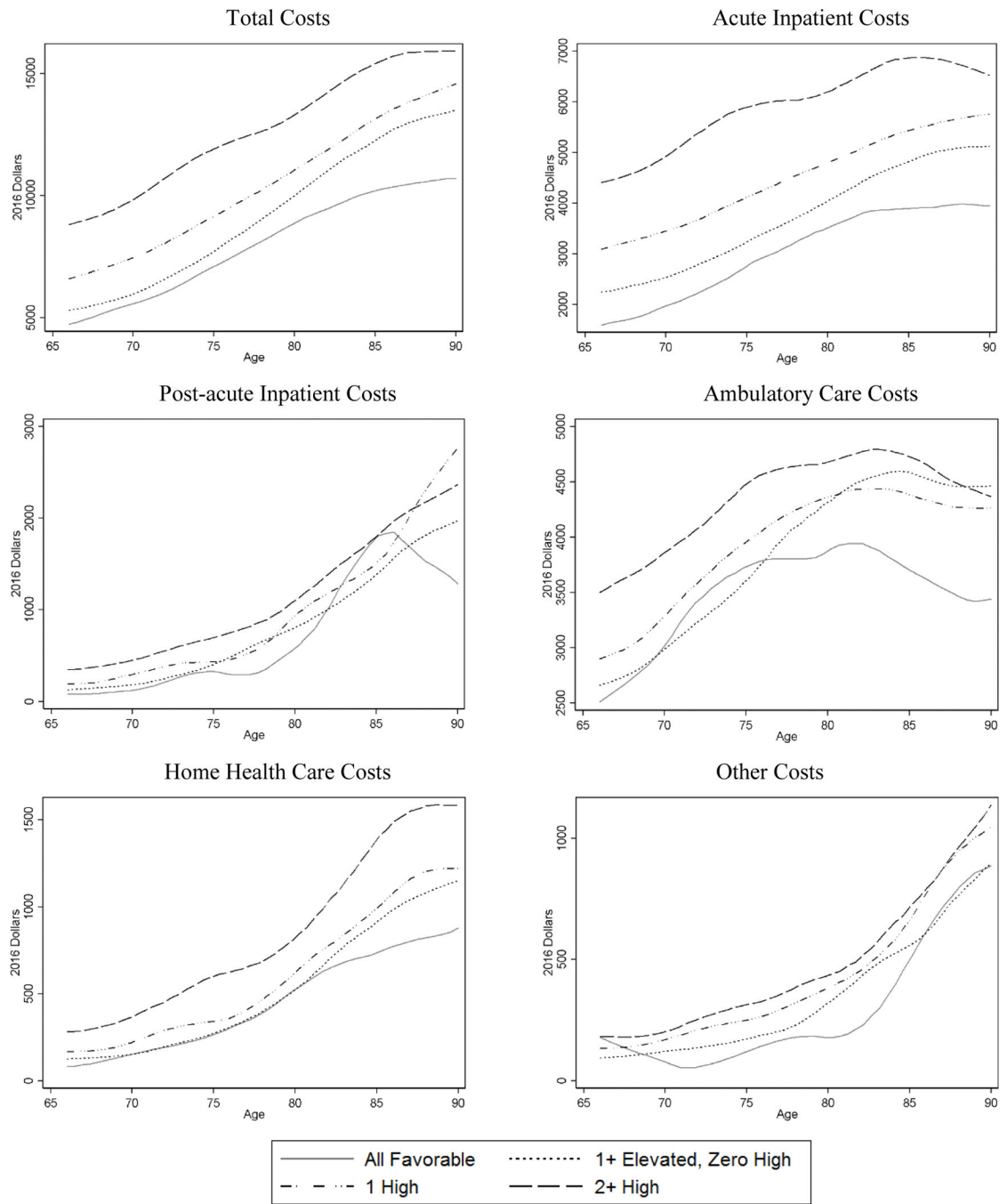
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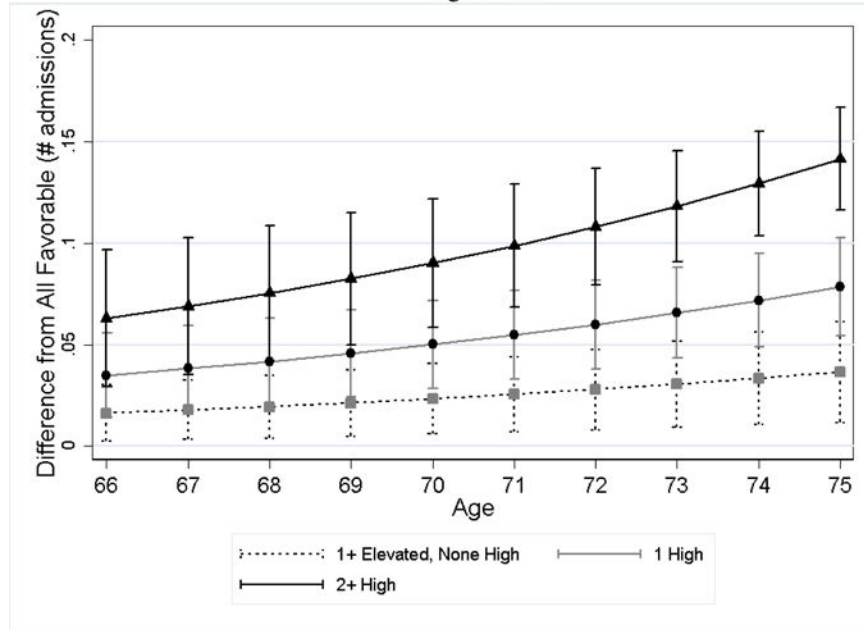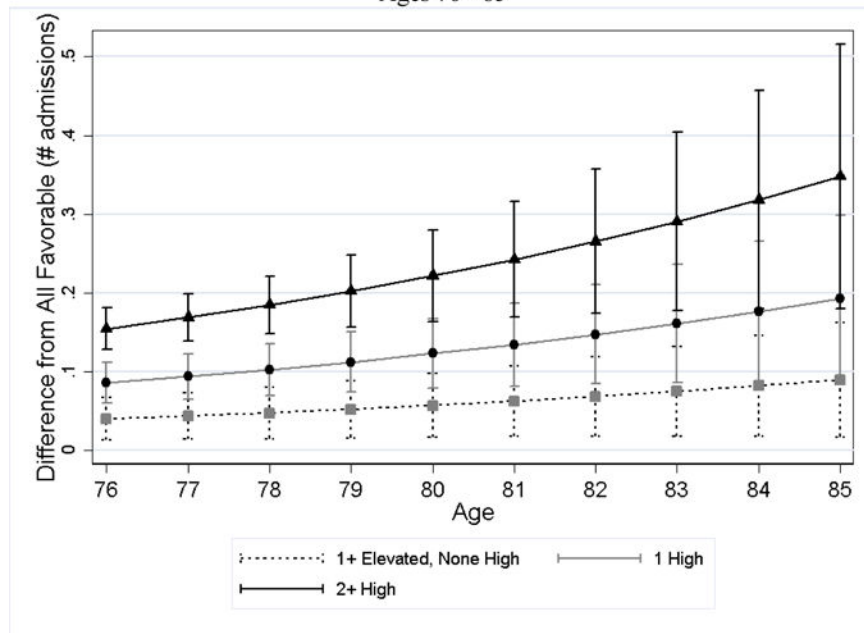
Figure 1.
Average Annual Medical Care Costs by Age and CVH Strata

a. Acute Inpatient Admissions
Ages 66-75

Ages 76 - 85

b. Acute Inpatient Length of Stay
Ages 66 - 75
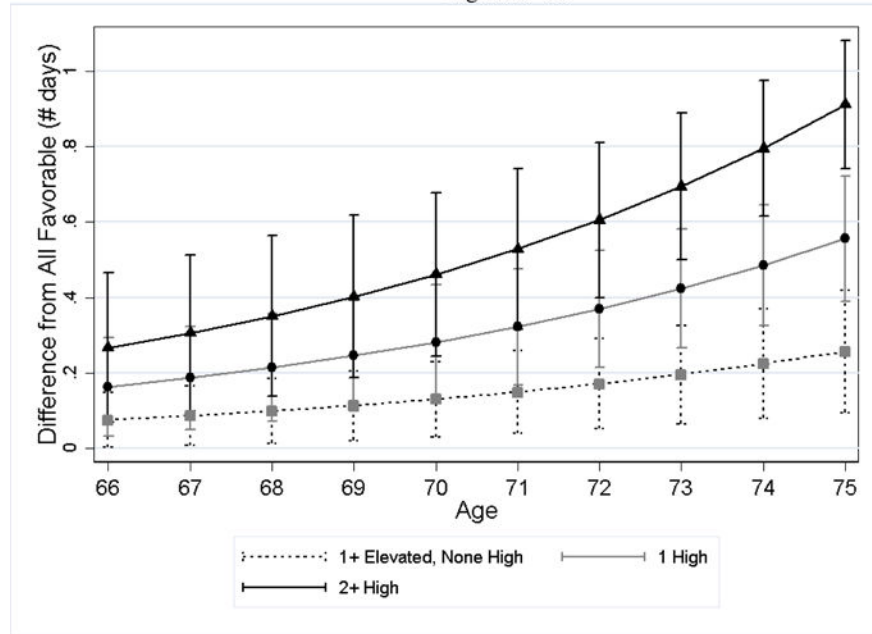

Ages 76 - 85

c. Post-Acute Inpatient Admissions
Ages 66 - 75

Ages 76 - 85

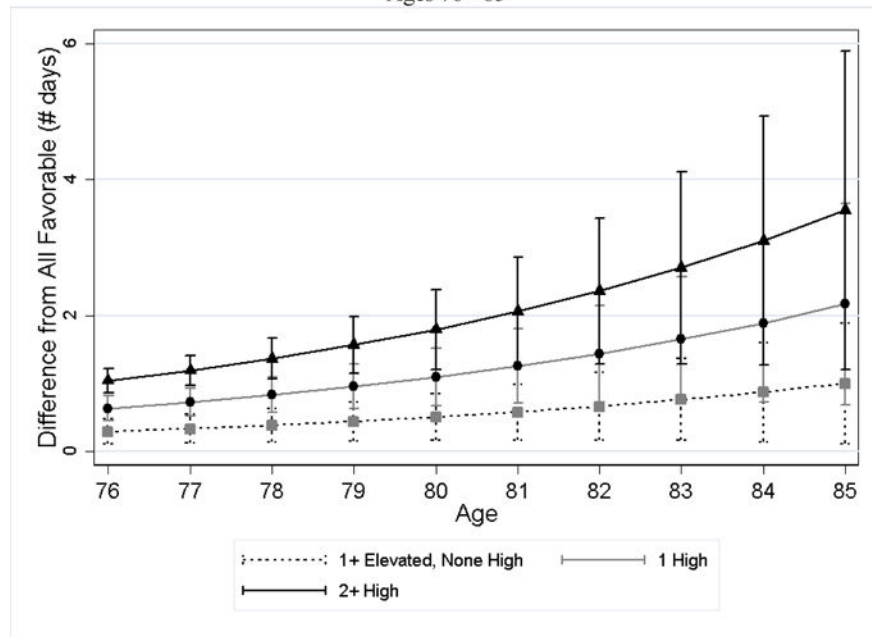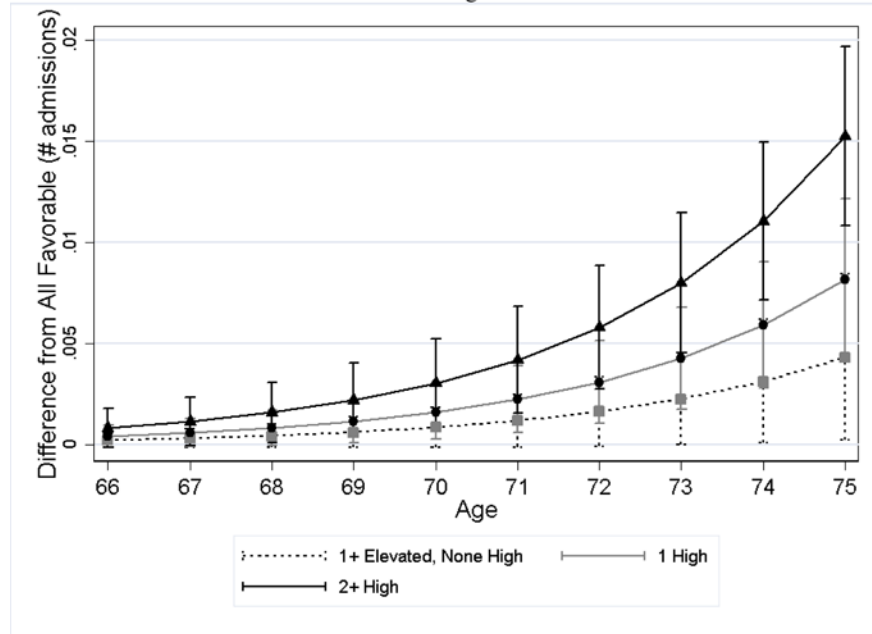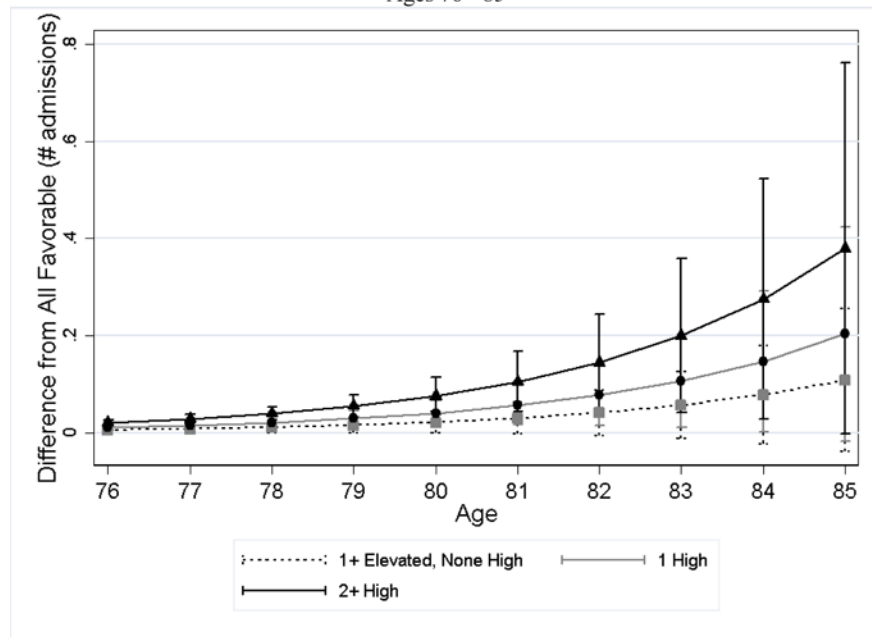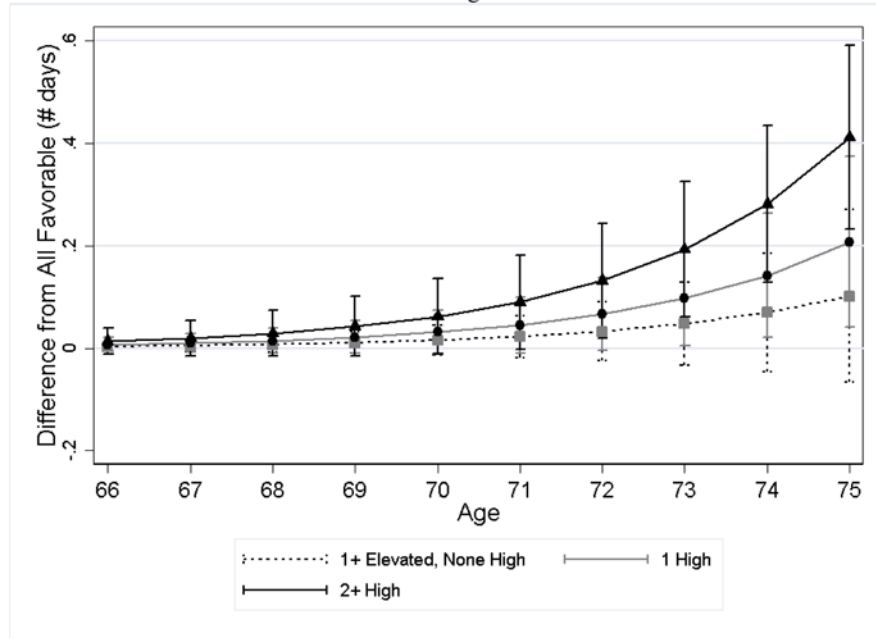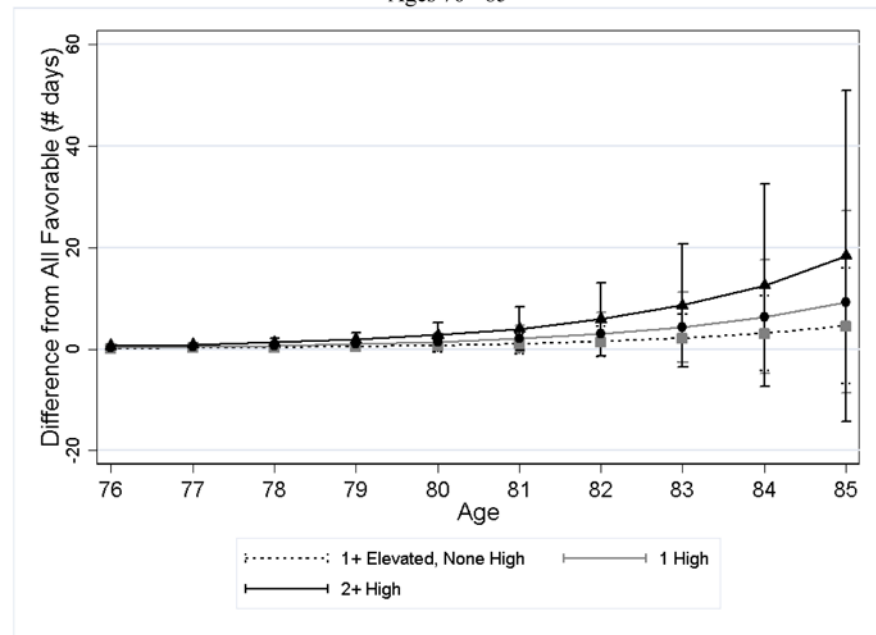d. Post-Acute Inpatient Length of Stay
Ages 66 - 75

Ages 76 - 85

e. Ambulatory Care Visits
Ages 66 - 75

Ages 76 - 85

f.   Home Health Care Visits
Ages 66 - 75
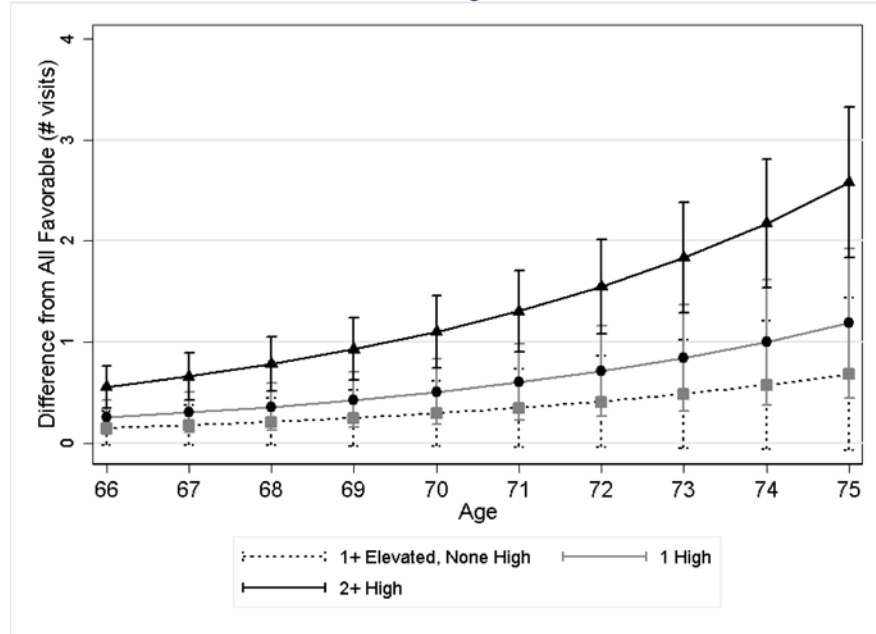
Ages 76 - 85
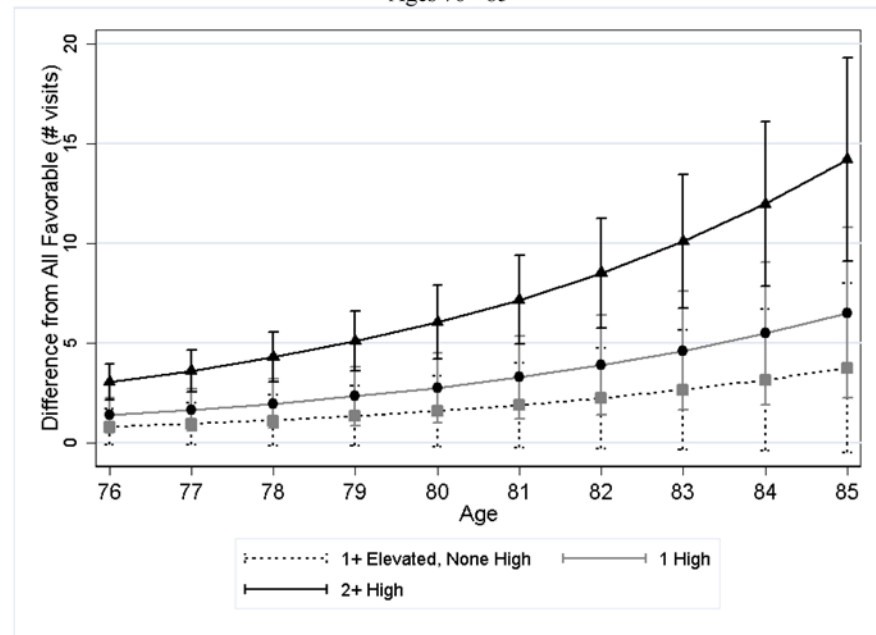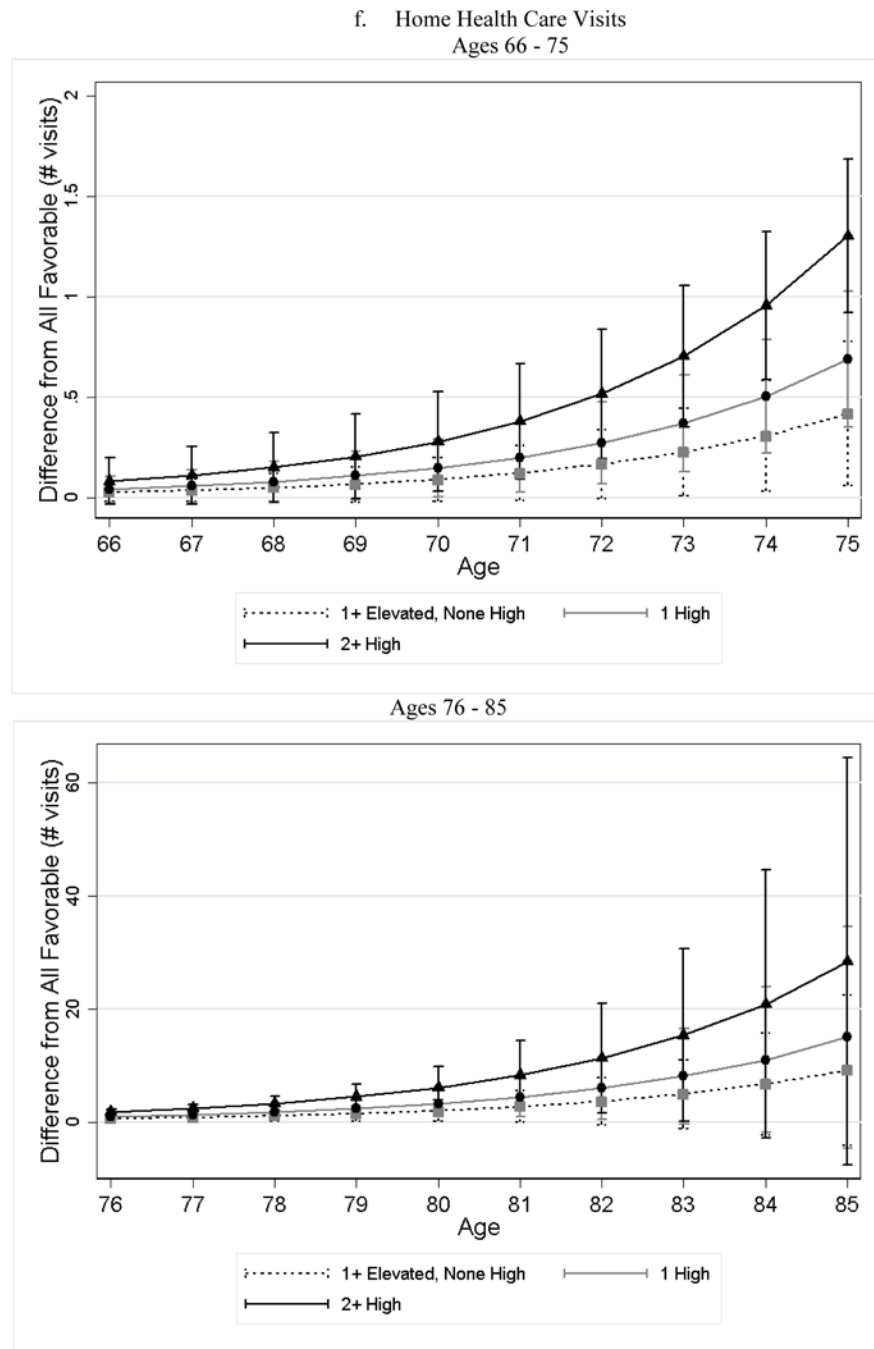
Figure 2.
Estimated Differences in Utilization between Less Favorable CVH and All Favorable by Age

Table 1.

Definitions of Favorable, Borderline, and High Levels of Cardiovascular Risk Factors

	Blood Pressure	Cholesterol	Diabetes	BMI	Smoking
Favorable	Untreated SBP 120 mm Hg and DBP 80 mm Hg	Untreated serum cholesterol < 200 mg/dL (<5.17 mmol/L)	No diabetes	BMI < 25	Non-smoker
Elevated but not High	Untreated SBP 121–139 or DBP 81–89	Untreated serum cholesterol 200–239 mg/dL (5.17 – 6.18 mmol/L)	No diabetes	BMI 25.0–29.9	Non-smoker
High	SBP 140 mm Hg or DBP 90 mm Hg or taking antihypertensive medications	Serum cholesterol level 240 mg/dL (6.21 mmol/L) or taking cholesterol-lowering medication	Diabetes	BMI 30	Current Smoker

Note: we followed the definition used in previous study by Allen NB, Zhao L, Lei L, et al. Favorable Cardiovascular Health, Compression of Morbidity and Healthcare Costs: 40-Year Follow-up of the Chicago Heart Association Detection Project in Industry. Circulation. 2017;135(18): 1693–1701. doi: 10.1161/CIRCULATIONAHA.116.026252.

Table 2.

Percent Distribution of Cardiovascular Risk Factors at Baseline by CVH Strata

	Blood Pressure	Cholesterol	Diabetes	BMI	Smoking
All Favorable	Untreated SBP 120 mm Hg and DBP 80 mm Hg	Untreated serum cholesterol < 200 mg/dL (<5.17 mmol/L)	No diabetes	BMI < 25	Non-smoker
(% of stratum)	100%	100%	100%	100%	100%
1+ Elevated, None High	Untreated SBP 121–139 or DBP 81–89	Untreated serum cholesterol 200–239 mg/dL (5.17 – 6.18 mmol/L)	No diabetes	BMI 25.0–29.9	Non-smoker
(% of Stratum)	60.7%	51.5%	100%	54.3%	100%
1 High	SBP 140 mm Hg or DBP 90 mm Hg or taking antihypertensive medications	Serum cholesterol level 240 mg/dL (6.21 mmol/L) or taking cholesterol-lowering medication	Diabetes	BMI 30	Current Smoker
(% of stratum)	46.3%	9.8%	0.9%	5.0%	38.1%
2+ High	SBP 140 mm Hg or DBP 90 mm Hg or taking antihypertensive medications	Serum cholesterol level 240 mg/dL (6.21 mmol/L) or taking cholesterol-lowering medication	Diabetes	BMI 30	Current Smoker
(% of stratum)	84.8%	42.2%	4.4%	32.7%	62.0%

Table 3.

Summary Statistics by CVH Strata

		CVH Strata				
		All Favorable	**1+ Elevated, None High**	**1 High**	**2 + High**	**P-value**
Sample Characteristics:						
Avg. Age at Follow-up (years)		74.5	75.8	76.0	76.3	<0.001
Female, %		61.9	41.1	41.6	36.6	<0.001
White, %		88.2	91.5	90.6	90.7	0.194
Black, %		6.3	5.2	6.6	6.9	0.005
Avg. Age at CV Risk Measurement (years)		37.9	41.2	42.5	44.3	<0.001
With a High School Degree, %		34.6	34.6	38.5	39.9	<0.001
With a More than High School Degree, %		55.6	52.0	43.6	35.7	<0.001
Utilization and Costs:						
Avg. No. of Acute Inpatient Admissions		0.19	0.24	0.29	0.38	<0.001
Avg. Acute Inpatient Length of Stay (days)		0.91	1.2	1.6	2.1	<0.001
Avg. No. of Post-acute inpatient admissions		0.04	0.04	0.05	0.07	<0.001
Avg. Post-acute inpatient Length of Stay (days)		0.97	1.3	1.5	1.9	<0.001
Avg. No. of Ambulatory Care Visits		14.6	15.4	15.8	17.1	<0.001
Avg. No. of Home Health Visits		1.4	2.0	2.5	3.8	<0.001
Total Costs, $	Median	1,548	1,819	1,854	2,241	<0.001
	Mean	6,903	8,312	9,613	12,111	<0.001
Acute Inpatient Costs, $	Median	0	0	0	0	–
	Mean	2,601	3,378	4,202	5,742	<0.001
Post-acute Inpatient Costs, $	Median	0	0	0	0	–
	Mean	454	628	746	948	<0.001
Ambulatory Care Costs, $	Median	1,464	1,679	1,665	1,906	<0.001
	Mean	3,343	3,631	3,806	4,298	<0.001
Home Health Care Costs, $	Median	0	0	0	0	–
	Mean	317	405	498	723	<0.001
Other Costs [*], $	Median	0	0	0	0	–
	Mean	187	270	361	401	<0.001
Sample Size (person-year)		8,226	34,945	64,980	50,155	<0.001
Number of CHA Participants		951	3,496	7,040	5,708	<0.001

Notes: Total sample size is 158,306 person-years. Costs are measured in 2016 dollars. P-values are obtained from Wald tests for the equality of the sample characteristics among the four risk strata.

*Other costs include costs for hospice care and durable medical equipment.

Table 4.

Differences in Annual Medicare Care Utilization Per Person between Less Favorable CVH and All Favorable (N = 158,306)

	Acute Inpatient		Post-acute Inpatient		Ambulatory Care	Home health
	No. of Admissions	Length of Stay	No. of Admissions	Length of Stay	No. of Visits	No. of Visits
Panel A: Overall						
All Favorable (ref. mean)	0.19	0.91	0.04	0.97	14.57	1.41
Marginal effect from ref.; Mean [SE]						
1+ Elevated, None High	0.04 ***	0.29 ***	0.006 **	0.15	0.80	0.56 **
	(0.01)	(0.09)	(0.003)	(0.12)	(0.46)	(0.24)
1 High	0.09 ***	0.63 ***	0.01 ***	0.30 **	1.40 ***	0.93 ***
	(0.01)	(0.09)	(0.003)	(0.12)	(0.44)	(0.22)
2 + High	0.15 ***	1.03 ***	0.02 ***	0.59 ***	3.04 ***	1.76 ***
	(0.01)	(0.09)	(0.003)	(0.12)	(0.45)	(0.22)
Panel B: P-values on the Interaction Term between CVH and Female Indicator						
All Favorable	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
1+ Elevated, None High	0.94	0.47	0.95	0.47	0.46	0.78
1 High	0.95	0.59	0.93	0.56	0.37	0.93
2 + High	0.91	0.78	0.82	0.60	0.06	0.73

Notes: Each column within a panel is from a separate regression. The sample size for each regression is 158,306. Panel A shows coefficients (marginal effects calculated at the mean of covariates) and cluster-robust standard errors (in parenthesis) obtained from negative binomial models. The coefficients in Panel A represent the per person difference in the dependent variable between less favorable CVH strata and all favorable CVH strata. In Panel B, we estimated separate models that also included the interaction term between CVH and the female indicator and the values in cells are the p-values on the interaction terms. All regressions also control for age at follow-up, state of residence, year, baseline age, race, sex, baseline education, and whether the participant died during the year.

**
p-value<0.05

***
p-value<0.01

Table 5.

Differences in Annual Medical Care Costs between Less Favorable CVH and All Favorable (N = 158,306)

	Quantiles Regressions						GLM
	Q25	Q50	Q75	Q90	Q95		
Total Costs							
All Favorable (ref., $)	416	1,548	4,844	16,962	35,084		6,903
Marginal effect from ref.; Mean [SE]							
1+ Elevated, None High	89 ***	207 ***	368	1,266	4,001 ***		1,157 ***
	(30)	(66)	(189)	(809)	(1,334)		(440)
1 High	82 ***	282 ***	892 ***	4,438 ***	10,219 ***		2,429 ***
	(28)	(64)	(187)	(839)	(1,226)		(425)
2 + High	164 ***	640 ***	3,019 ***	13,087 ***	21,572 ***		4,628 ***
	(30)	(72)	(240)	(989)	(1,403)		(428)
CVD-related Costs							
All Favorable (ref., $)	0	0	0	380	1,116		616
Marginal effect from ref.; Mean [SE]							
1+ Elevated, None High	–	–	1	34	27		743 ***
			(2)	(17)	(52)		(197)
1 High	–	–	7 ***	145 ***	424 ***		1,140 ***
			(2)	(32)	(98)		(190)
2 + High	–	–	175 ***	1,058 ***	7,319 ***		1,758 ***
			(13)	(78)	(633)		(186)
Non-CVD-related Costs							
All Favorable (ref., $)	391	1,448	4,464	14,810	31,784		6,287
Marginal effect from ref.; Mean [SE]							
1+ Elevated, None High	83 ***	188 ***	274	512	3,136 **		665
	(26)	(62)	(168)	(671)	(1,268)		(371)
1 High	67 ***	226 ***	636 ***	2,825 ***	7,260 ***		1,507 ***

	Quantiles Regressions					GLM
	Q25	Q50	Q75	Q90	Q95	
	(25)	(59)	(164)	(692)	(1,324)	(359)
2 + High	121***	479***	1,886***	8,239***	15,677***	3,013***
	(26)	(64)	(200)	(827)	(1,435)	(363)
Acute Inpatient Costs						
All Favorable (ref., $)	0	0	0	6,386	17,137	2,601
Marginal effect from ref.; Mean [SE]						
1+ Elevated, None High	–	–	–	322	2,146**	716***
				(305)	(956)	(268)
1 High	–	–	–	2,467***	6,152***	1,496***
				(438)	(983)	(258)
2 + High	–	–	–	7,676***	13,254***	2,673***
				(493)	(1,053)	(257)
Post-acute Inpatient Costs						
All Favorable (ref., $)	0	0	0	0	0	454
Marginal effect from ref.; Mean [SE]						
1+ Elevated, None High	–	–	–	–	9	217***
					(6)	(69)
1 High	–	–	–	–	11	313***
					(6)	(66)
2 + High	–	–	–	–	21***	494***
					(7)	(66)
Ambulatory Care Costs						
All Favorable (ref., $)	405	1,464	3,943	7,746	11,766	3,343
Marginal effect from ref.; Mean [SE]						
1+ Elevated, None High	83***	171***	242	593	882**	201
	(28)	(61)	(142)	(311)	(379)	(160)
1 High	70***	200***	399***	1,182***	1,704***	419***
	(27)	(58)	(137)	(309)	(385)	(156)
2 + High	137***	452***	1,070***	2,502***	3,511***	921***
	(28)	(63)	(145)		(413)	(157)
Home Health Costs						
All Favorable (ref., $)	0	0	0	0	144	317

	Quantiles Regressions									GLM
	Q25		Q50		Q75		Q90		Q95		
Marginal effect from ref.; Mean [SE]											
1 Elevated, None High	–		–		–		4**		21		99**
							(1)		(12)		(50)
1 High	–		–		–		5***		37***		200***
							(1)		(13)		(50)
2 + High	–		–		–		12***		1,310***		356***
							(2)		(173)		(47)
Other Costs											
All Favorable (ref., $)	0		0		0		85		282		187
Marginal effect from ref.; Mean [SE]											
1+ Elevated, None High	–		–		–		8***		26***		62
							(2)		(7)		(48)
1 High	–		–		–		15***		82***		136***
							(2)		(18)		(45)
2 + High	–		–		–		116***		415***		175***
							(18)		(50)		(44)

Notes: Coefficients (cluster-robust standard errors in parenthesis) are obtained from quantile regressions. Each column by outcome is one regression. The sample size for each regression is 158,306. All regressions also control for age at follow-up, state of residence, year, baseline age, race, sex, baseline education, and whether the participant died during the year.

**
p<0.05

***
p<0.01s