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David A. Dorr
Oregon Health & Science University

Sheila Markwardt
Oregon Health & Science University

Michelle Bobo
Oregon Health & Science University

Heather G. Allore
Yale University

Anda Botoseneanu
University of Michigan-Dearborn

See next page for additional authors

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The extent and burden of high multimorbidity on older adults in the US: a descriptive analysis of Medicare beneficiaries

David A. Dorr[1*], Sheila Markwardt[2], Michelle Bobo[1], Heather G. Allore[3], Anda Botoseneanu[4], Jason T. Newsom[5], Corey Nagel[6] and Ana R. Quiñones[2,7]

Abstract

Background The impact of multimorbidity (≥ 2 chronic diseases) on the well-being of older adults is substantial but variable. The burden of multimorbidity varies by the number and kinds of conditions, and timing of onset. The impact varies by age, race, ethnicity, socioeconomic status, and health indicators. Large scale longitudinal surveys linked to medical claims provide unique opportunities to characterize this variability.

Methods We analyzed Medicare-linked Health and Retirement Study data for respondents 65 and older with 3 or more years of fee-for-service coverage ($n = 17{,}199$; 2000–2016). We applied standardized claims algorithms for operationalizing 21 chronic diseases. We compared multimorbidity levels, demographics, and outcomes at baseline and over time and escalation to high multimorbidity levels (≥ 5 conditions).

Results At baseline, 51.2% had no multimorbidity, 36.5% had multimorbidity, and 12.4% had high multimorbidity. Loss of function, cognitive decline, and higher healthcare utilization were up to ten times more prevalent in the high multimorbidity group. Greater rates of high multimorbidity were seen among non-Hispanic Black and Hispanic groups, those with lower wealth, younger birth cohorts, and adults with obesity. Rates of transition to high multimorbidity varied greatly and was highest among Hispanic and respondents with lower education.

Conclusions The development and progression of multimorbidity in old age is influenced by many factors. Higher levels of multimorbidity are associated with sociodemographic characteristics, suggesting possible mitigation strategies.

Keywords Multimorbidity, Epidemiology, Longitudinal analysis, Aging

*Correspondence:
David A. Dorr
dorrd@ohsu.edu
[1] Department of Medical Informatics & Clinical Epidemiology, Oregon Health & Science University, 3181 SW Sam Jackson Park Road, Mail Code: FM, Portland, OR 97239, USA
[2] OHSU-PSU School of Public Health, Oregon Health & Science University, Portland, OR, USA
[3] Departments of Medicine and Biostatistics, Yale University, New Haven, CT, USA
[4] College of Education, Health, and Human Services, University of Michigan-Dearborn, Dearborn, MI, USA
[5] Department of Psychology, Portland State University, Portland, OR, USA
[6] College of Nursing, University of Arkansas for Medical Sciences, Little Rock, AR, USA
[7] Department of Family Medicine, Oregon Health & Science University, Portland, OR, USA

Introduction

Chronic diseases have supplanted acute problems in their prominence, as well as in the challenges they present to healthcare systems worldwide. Multimorbidity (≥2 chronic diseases) is very common, particularly among older adults. In the United States, 71.7% of Medicare beneficiaries have multimorbidity, and 17.3% have high levels of multimorbidity (≥5 chronic diseases) [1]. Persons with multimorbidity have constituent diseasesthat may have complicated treatment plans; these plans cause significant strain to affected individuals, their families, and clinical providers [2, 3]. A better understanding of the ways in which multimorbidity presents and changes into old age is needed to develop strategies and enact policies that can mitigate its burden, impact, and costs [4, 5].

It is challenging to trace the development and progression of multimorbidity because the trajectories of aging are diverse and multifactorial. While the majority of people develop many chronic diseases as they get older, others remain relatively healthy into very old age [6]. The impact of heterogeneous patterns of aging and ongoing accumulation of multimorbidity is highly variable. Over time, multimorbidity may lead to additional adverse outcomes including disability, frailty, cognitive decline, and diminishing health-related quality of life [7, 8]. The number, severity, and patterning of chronic diseases are influential in later-life sequelae as are self-assessments of overall health and functional status; the latter of which may be more proximal to predicting adverse outcomes such as mortality [9].

At a community level, there are significant disparities in rates of developing multimorbidity across populations [7, 10–15]. Women, minoritized racial and ethnic groups, and persons with low socioeconomic status are more likely to develop multimorbidity at younger ages compared with their sex, racial/ethnic, and socioeconomic counterparts. Additionally, there is evidence that earlier onset of multimorbidity is occurring in younger compared with older birth cohorts [11, 16]. In the US, both the percentage of people with multimorbidity and associated healthcare spending increased significantly from 2006–2010, partially reflecting these demographic changes and portending rises in healthcare costs [1].

For healthcare systems, multimorbidity is associated not only with increased healthcare costs but also with preventable healthcare utilization. Individuals with multimorbidity generate four times as much healthcare spending per capita as those without chronic diseases, and those with high multimorbidity generate nearly 14 times as much as those without multimorbidity. Over 70% of all inpatient stays involve persons with multimorbidity, 38.5% among those with high multimorbidity [1].

The objective of this paper is to describe the onset and association of key multimorbidity categories (none; multimorbidity: 2–4 diseases; high multimorbidity: ≥5 diseases), and to assess the associations of these categories with important socioeconomic, health, and healthcare factors using a large representative population health study in the US linked to Medicare claims [8, 17]. The results of this paper may be helpful to researchers interested in modeling trends and association of multimorbidity over time, providing example thresholds. In addition, those developing interventions to mitigate the effects of multimorbidity over time may benefit from understanding trends with important demographic, social, and healthcare characteristics.

Methods

We evaluated up to 24 years (1992–2016) of longitudinal data from the Health and Retirement Study (HRS) (http://hrsonline.isr.umich.edu/), a nationally-representative longitudinal study of non-institutionalized middle- and older-aged adults. Respondents and their partners are assessed biennially from study entry until death. We used the HRS-Medicare linked data to evaluate fee-for-service (FFS) claims for chronic disease diagnoses and utilization data. Medicare Parts A & B are U.S. government-sponsored insurance programs that provide coverage for persons aged ≥65 and the disabled. The coverage includes payment for health care utilization (inpatient, outpatient, and emergency department visits) and health care provider charges. The diagnosis codes used in this analysis were recorded for billing purposes for the provision of these services and provide more granular detail on specific chronic diseases than those reported in the public HRS data. All data procedures were carried out in accordance with relevant guidelines and regulations. The study protocol was approved by Oregon Health and Science University—Research Integrity Office Institutional Review Board (STUDY00017034, STUDY00019414).

Study population

Of the 43,216 HRS age-eligible respondents living in the community and with a positive survey weight for at least one survey wave, 25,881 had linked Medicare claims. Of these, 22,791 were FFS Medicare beneficiaries. To allow for sufficient data to calculate chronic disease status using the Medicare Chronic Condition Warehouse (CCW) algorithms we limited our sample to participants with 3 or more years of FFS claims; this also meant our earliest assessment was at age 67, or 3 years after Medicare age-eligibility. The final analytic sample consisted of 17,199 respondents (Supplementary Fig. 1).

Variables

Multimorbidity categories

The main outcome variable in this study was multimorbidity. Chronic diseases were defined from coded diagnoses from Medicare claims, then categorized by the US Department of Health and Human Services Multimorbidity Framework and operationalized using Centers for Medicare and Medicaid Services (CMS) CCW algorithms [18, 19] These 21 conditions are validated to be representative of a common set of prevalent and impactful diseases and are frequently used to operationalize multimorbidity among older adults [20, 21] (Supplementary Table 5; Supplementary Fig. 2).

Multimorbidity was then operationalized as a simple count of chronic diseases and further categorized as: no multimorbidity (0–1 diseases), multimorbidity (2–4 diseases), and high multimorbidity (≥ 5 diseases). We determined the cut-offs for low and high multimorbidity based on prior work [22, 23] and given the concentration of outcomes in those with ≥ 5 diseases.

Race/ethnicity categories

The HRS uses two successive questions to assess race/ethnicity: 1) "Do you consider yourself Hispanic or Latino?" and 2) "Do you consider yourself primarily White or Caucasian, Black or African American, American Indian, or Asian, or something else?" We created four mutually-exclusive groups: non-Hispanic White (White), non-Hispanic Black (Black), Hispanic, and non-Hispanic Other (Other). Despite limited information to differentiate the heterogeneity of racial and ethnic identities comprising the non-Hispanic Other group, we include this broad group in descriptive analyses.

Sociodemographic factors

Sociodemographic covariates included age categories (67–69, 70–74, 75–79, and ≥ 80 years) ascertained from Medicare claims (Supplementary Tables 1–4). Female sex, being in a coupled partnership, education (years, and educational attainment categories: less than high school, high school diploma, some college, college/post-college), household wealth quartiles, and whether a proxy ever provided an interview were ascertained from HRS surveys.

Health status

HRS surveys also provide information on body mass index (BMI), calculated according to the established formula, BMI = weight[pounds] × 703 / height^2 [inches], using self-reported height and weight at first observation. BMI was categorized as follows: underweight (< 18.5 kg/m^2), healthy weight (18.5–24.9 kg/m^2), overweight (25.0–29.9 kg/m^2), obese (≥ 30.0 kg/m^2). Functional status was assessed with self-reported limitations in activities of daily living (ADL; dressing, walking across a room, eating, bathing, toileting, transferring from bed) and instrumental activities of daily living (IADL; meal preparation, grocery shopping, using a telephone, taking medication, managing money). A specific ADL or IADL limitation was noted if the respondent reported difficulty performing the task due to a health of memory problem, or if the respondent received help performing the task. ADLs and IADLs were summed (ADL range: 0–6; IADL range: 0–5; higher scores indicate greater limitations).

HRS assesses cognitive status using a variety of measures that can be combined into a single summary score and further categorized. In this study, we utilized the publicly-available HRS Langa-Weir contributed data set [24], which made use of imputed information for HRS cognitive measures and for proxy interviews. Measures in the Langa-Weir classification include: 1) immediate and delayed 10-noun free recall test to measure memory (0 to 20 points); 2) a serial sevens subtraction test to measure working memory (0 to 5 points); and 3) a counting backwards test to measure speed of mental processing (0 to 2 points). The Langa-Weir classification of cognitive status involves: normal (12 – 27); cognitively impaired but not demented (CIND) (7 – 11); and demented (0 – 6). Mortality was determined using date of death documented in Medicare claims.

Healthcare utilization

Healthcare utilization variables were ascertained with Medicare claims. Emergency department (ED) visits were identified among inpatient and outpatient claims using revenue center codes 0450–0459 and 0981 [25]. Unique inpatient hospitalizations were identified using a combination of admission date and provider identifiers with non-overlapping from and through dates [26]. ED visits and hospitalizations were enumerated annually.

Analysis

We used descriptive statistics to summarize sociodemographic, health and functional status, and healthcare utilization characteristics for Medicare beneficiaries at their first observation according to our three multimorbidity levels (no multimorbidity, multimorbidity, and high multimorbidity); we report frequencies and percentages for categorical variables, means and standard deviations for continuous variables, and incidence rates for event variables (Table 1). We assessed differences in sociodemographic, health status, and healthcare utilization across multimorbidity groups using chi-square tests for categorical variables, simple linear regression for continuous variables, or Poisson regression for count variables.

Table 1 Medicare fee-for-service beneficiary characteristics according to multimorbidity status at first observation

Characteristics	*Total* N = *17,199*	*No multimorbidity* N = *8,800 (51.2%)*	*Multimorbidity* N = *6,270* (36.5%)	*High multimorbidity* N = *2,129* (12.4%)	*p-value*[1]
Age category, n (%)					
67–69	11,210 (65.2)	4,702 (53.4)	4,607 (73.5)	1,901 (89.3)	< 0·001
70–74	2,764 (16.1)	1,853 (21.1)	779 (12.4)	132 (6.2)	
75–79	1,776 (10.3)	1,247 (14.2)	473 (7.5)	56 (2.6)	
80 +	1,449 (8.4)	998 (11.3)	411 (6.6)	40 (1.9)	
Female, n (%)	9,780 (56.9)	4,885 (55.5)	3,648 (58.2)	1,247 (58.6)	0·001
Coupled, n (%)[a]	9,350 (63.2)	4,642 (60.9)	3,520 (66.8)	1,188 (62.5)	< 0·001
Education (years), mean (SD)	11.6 (3.6)	11.4 (3.6)	11.7 (3.5)	11.5 (3.5)	< 0·001
Education category, n (%)[a]					
Less than high school	5,932 (34.8)	3,214 (36.8)	1,968 (31.7)	750 (35.4)	< 0·001
High school diploma	5,516 (32.4)	2,727 (31.3)	2,111 (34.0)	678 (32.0)	
Some college	2,833 (16.6)	1,391 (15.9)	1,081 (17.4)	361 (17.1)	
College diploma/post-college	2,765 (16.2)	1,394 (16.0)	1,044 (16.8)	327 (15.5)	
Race/ethnicity, n (%)[a]					
Non-Hispanic White	13,475 (78.8)	7,130 (81.5)	4,833 (77.7)	1,512 (71.3)	< 0·001
Non-Hispanic Black	2,282 (13.4)	1,038 (11.9)	899 (14.5)	345 (16.3)	
Hispanic	1,044 (6.1)	459 (5.2)	378 (6.1)	207 (9.8)	
Other race/ethnicity	289 (1.7)	122 (1.4)	111 (1.8)	56 (2.6)	
Household Nnet worth, n (%)[a]					
< $51,000	1,673 (23.3)	455 (19.8)	603 (18.5)	615 (37.9)	< 0·001
$51,000 to $186,000	1,713 (23.9)	534 (23.2)	794 (24.4)	385 (23.7)	
$186,000 to $495,900	1,736 (24.2)	575 (25.0)	836 (25.7)	325 (20.0)	
$495,900 +	2,053 (28.6)	737 (32.0)	1,019 (31.3)	297 (18.3)	
Ever proxy, n (%)[a]	3,341 (22.1)	2,053 (25.6)	996 (18.4)	292 (17.4)	< 0·001
Body Mass Index Category, n (%)[a]					
Underweight	340 (2.5)	228 (3.2)	83 (1.8)	29 (1.8)	< 0·001
Healthy weight	5014 (37.4)	3156 (44.5)	1493 (31.8)	365 (22.3)	
Overweight	5104 (38.0)	2715 (38.3)	1825 (38.8)	564 (34.5)	
Obese	2963 (22.1)	988 (13.9)	1299 (27.6)	676 (41.4)	
Number of conditions, mean (SD)	2.0 (2.2)	0.4 (0.5)	2.8 (0.8)	6.5 (1.7)	< 0·001
ADL deficits, ≥ 2, n (%)[a]	560 (8.3)	61 (3.0)	169 (5.4)	330 (20.6)	< 0·001
IADL deficits, ≥ 2, n (%)[a]	362 (5.4)	35 (1.7)	99 (3.2)	228 (14.2)	< 0·001
ADL/IADL deficits, ≥ 4, n (%)[a]	356 (5.3)	33 (1.6)	92 (2.9)	231 (14.4)	< 0·001
ED visits per 100 person-years in year of 1st obs	33.9	14.4	36.5	107.2	< 0·001
Hospitalizations per 100 person-years in year of 1st obs	22.7	7.9	26.5	76.3	< 0·001
Cognitive impairment category, n (%)[a]					
No cognitive impairment	5,491 (81.4)	1,694 (84.3)	2,630 (83.9)	1,167 (72.8)	< 0·001
CIND	940 (13.9)	263 (13.1)	395 (12.6)	282 (17.6)	
Demented	316 (4.7)	53 (2.6)	110 (3.5)	153 (9.6)	

[1] *p*-values are from chi-square tests for categorical variables, simple linear regression for continuous variables, or Poisson regression for count variables (rates of ED visits and hospitalizations)

[a] Frequencies may not add up to total in each group due to missing values or rounding

Rates of chronic disease and multimorbidity accumulation were calculated overall and by the following socioeconomic factors: race/ethnicity, sex, and education category (Table 2). Health status and utilization outcomes and chronic condition status were summarized using descriptive statistics for beneficiaries at their last observation according to multimorbidity category at last observation (Table 3). Multimorbidity and high multimorbidity categories at the last observation were further categorized as incident or prevalent multimorbidity.

Table 2 Rates of disease accumulation, multimorbidity, and high multimorbidity over the entire study period

	Chronic disease accumulation rate **(per 1,000 py)**[a]	***Multimorbidity incidence rate*** **(per 1,000 py)**[b]	***High multimorbidity incidence rate*** **(per 1,000 py)**[c]
Overall	416.6	116.7	83.5
Race/ethnicity			
Non-Hispanic White	418.8	168.2	82.3
Non-Hispanic Black	411.7	165.8	88.6
Hispanic	416.1	154.9	93.6
Other	368.2	147.8	84.2
Sex			
Male	415.6	158.4	80.8
Female	417.5	173.7	85.5
Education category			
Less than high school	472.9	176.6	91.4
High school diploma	400.4	163.5	81.6
Some college	385.9	161.3	80.7
College diploma/post-college	356.5	157.0	74.5

[a] Rate at which beneficiaries are accumulating chronic diseases; calculated for all beneficiaries

[b] Calculated for beneficiaries who did not have multimorbidity at their first observation

[c] Calculated for beneficiaries who did not have high multimorbidity at their first observation

Table 3 Health status and utilization outcomes at last observation according to incident or prevalent multimorbidity status at last observation

Outcomes at Last Observation	***Total*** **(n = *17,199*)**	***Multimorbidity Status at Last Observation***[a]				
		No Observed **MM** **(n = *1,524*)**[b]	***Incident MM*** **(n = *2,355*)**[c]	***Prevalent MM*** **(n = *2,042*)**[d]	***Incident High MM*** **(n = *9,149*)**[e]	***Prevalent High MM*** **(n = *2,129*)**[f]
ADL deficits, ≥ 2, n (%)	3,014 (26.3)	58 (6.7)	272 (17.4)	111 (8.0)	2,123 (34.7)	450 (29.6)
IADL deficits, ≥ 2, n (%)	2,822 (25.2)	46 (5.3)	258 (16.6)	70 (5.0)	2,123 (34.7)	385 (25.4)
ADL/IADL deficits, ≥ 4, n (%)	2,743 (24.0)	38 (4.4)	247 (15.9)	72 (5.2)	2,011 (32.9)	375 (24.7)
ED visits per 100 person-years in year of last obs	102.6	19.8	61.7	37.0	129.4	155.3
Hospitalizations per 100 person-years in year of last obs	78.2	10.5	50.6	24.4	102.2	105.6
Cognitive impairment category, n (%)						
No cognitive impairment	6,230 (54.4)	644 (74.6)	905 (58.0)	1,063 (76.4)	2,720 (44.4)	898 (59.0)
Impaired not demented, CIND	2,752 (24.0)	157 (18.2)	372 (23.8)	244 (17.5)	1,625 (26.5)	345 (23.2)
Demented	2,479 (21.6)	62 (7.2)	283 (18.1)	85 (6.1)	1,780 (29.1)	269 (17.7)
Deceased, n (%)	8,742 (50.8)	292 (19.2)	1,091 (46.3)	418 (20.5)	5,934 (64.9)	5,934 (47.3)

Abbreviations: *MM* Multimorbidity, *ADL* Activities of Daily Living, *IADL* Independent Activities of Daily Living, *ED* Emergency Department, *CIND* Cognitive Impairment with No Dementia

[a] Incident multimorbidity is defined by the development of either multimorbidity or high multimorbidity during follow-up; prevalent multimorbidity is defined as existing multimorbidity or high multimorbidity at first observation

[b] No observed multimorbidity: mean follow-up time = 5.03 years (3.97 years)

[c] Incident multimorbidity: mean follow-up time = 9.19 years (5.01 years)

[d] Prevalent multimorbidity: mean follow-up time = 5.29 years (3.89 years)

[e] Incident high multimorbidity: mean follow-up time = 12.85 years (5.66 years)

[f] Prevalent high multimorbidity: mean follow-up time = 6.19 years (4.19 years)

Incident multimorbidity was defined by the development of multimorbidity during the 24-year study period (i.e., new onset during follow-up); prevalent multimorbidity is defined as existing multimorbidity (i.e., existing multimorbidity at first observation). Finally, we determined the average number of years beneficiaries spent in each of the three multimorbidity categories and their final study status (e.g. entered into managed care and were no longer observed, followed until the end of study, or deceased) by baseline age and baseline multimorbidity (Table 4).

We visualized proportional distribution of individuals with multimorbidity combinations by an index disease at first and last observation using a stacked bar chart (Fig. 1). We also generated an alluvial plot to illustrate the flow from no multimorbidity to multimorbidity to high multimorbidity and death for individuals throughout their ages under observation (Fig. 2). The sizes of the vertical bars in the alluvial plot are proportional to the number of participants represented by each category.

Results

Multimorbidity at first and last observation overall, by cohort, and sex

From Table 1, 51.2% (8,800) of the 17,199 patients had no multimorbidity, 36.5% (6,270) had multimorbidity, and 12.4% (2,129) had high multimorbidity at first observation. Among those with high multimorbidity at the outset, the average number of conditions was 6.5 (SD = 1.7). By the last observation of the study period (Table 3), 8.8% (1,524) beneficiaries had no observed multimorbidity; 25.5% (4,397) had multimorbidity; and 65.5% (11,278) had high multimorbidity.

As shown in Table 1, the youngest age category at study entry (67–69 years) represented the highest proportion with high multimorbidity (17%) and multimorbidity (41%), and lowest with no multimorbidity (42%). The oldest group at first observation, age 80+, had a much larger proportion of respondents with no multimorbidity (998/1449 who entered at 80 or later, or 69%). The older group at first observation were largely from an older birth cohort (1930s or earlier cohort) and had lower overall levels of multimorbidity than younger birth cohorts (Supplementary Table 2). Females were 56.9% of the study population, comprising 58.2% of the multimorbidity category and 58.6% of the high multimorbidity category.

Race/ethnicity and wealth

There were clear differences among racial and ethnic groups. The initial study population was 78.8% White, 13.4% Black, 6.1% Hispanic, and 1.7% identified as other race/ethnicity. Hispanic beneficiaries comprised 9.8% and Black beneficiaries 16.3% of the high multimorbidity group, while White beneficiaries were 81.5% of the no multimorbidity group.

Coupled relationship status and years of education had modest but significant differences with multimorbidity categories, while wealth demonstrated large differences. Individuals in the lowest wealth quartile (< $51,000) comprised 37.9% of those with high multimorbidity, compared with less than 24% for those in the next highest wealth quartile ($51,000—$186,000).

Clinical characteristics and multimorbidity status

BMI differed between multimorbidity categories. Healthy weight individuals were 37.2% of the initial population, 44.4% of the no multimorbidity category and only 22.3% of the high multimorbidity category. Obese individuals had a much higher proportion of high multimorbidity (41.1% compared with 22.1% of the study population) and were less likely to have no multimorbidity (14.0%).

High multimorbidity was associated with diminishing independence and lower health status and utilization at baseline. The prevalence of dementia was 9.6% in individuals with high multimorbidity, compared with 2.6% and 3.5% for no or multimorbidity, respectively. Participants with high multimorbidity had greater prevalence of functional loss, with 20.6% having ≥ 2 ADL limitations and 14.2% with ≥ 2 IADL limitations compared with 5.4% and 3.2% in the no and multimorbidity group, respectively. Hospitalizations and emergency department visits show a similar pattern. Participants with high multimorbidity had nearly 10 times the rate of hospitalization compared with those with no multimorbidity (76.3 versus 7.9 admissions per 100 person years [py]), and seven times the rate of ED visits (107.2 versus 14.4 visits per 100 py).

Frequency of conditions in multimorbidity groups

Certain conditions are over-represented in the high multimorbidity group (red), especially cardio- and cerebrovascular illnesses, while conditions like cancer were more prevalent in the multimorbidity group (Fig. 1; Supplemental Table 5). Hypertension, cancer, and rheumatoid/osteoarthritis were the conditions registering the highest relative proportion to occur alone (white portions Fig. 1) or with only one other condition at first observation, while schizophrenia was the condition with the highest relative proportion co-occurring with at least 4 additional conditions (i.e., high multimorbidity) at first observation.

Table 2 demonstrates the differences in the rates at which individuals accumulated additional diseases and incidence rates for transitioning into the multimorbidity and high multimorbidity categories. Across other demographic characteristics, those with less than a high school education moved into high multimorbidity at a rate of 91.4 per 1,000 person-years, compared with 74.5 for

Table 4 Average time spent in each multimorbidity category and distribution of 'final status' according to baseline age and baseline multimorbidity status

		Average number of years in each multimorbidity category during follow-up				*Status at last observation*		
Baseline age	*Baseline MM status*	*No MM*	*MM*	*High MM*	*Final Status*	*No MM*	*MM*	*High MM*
67–69	**No multimorbidity** (***N***=4702)	4.30 (3.61)	5.45 (3.88)	6.36 (4.48)	**N**	1041	1295	2366
					Managed care	571 (54.9)	436 (33.7)	329 (13.9)
					End of follow-up	323 (31.0)	490 (37.8)	657 (27.8)
					Mortality	147 (14.1)	369 (28.5)	1380 (58.3)
	Low multimorbidity (***N***=4607)	-	4.90 (3.65)	6.78 (4.58)	**N**	-	1669	2938
					Managed care	-	710 (42.5)	464 (15.8)
					End of follow-up	-	729 (43.7)	1217 (41.4)
					Mortality	-	230 (13.8)	1257 (42.8)
	High multimorbidity (***N***=1901)	-	-	6.20 (4.19)	**N**	-	-	1901
					Managed care	-	-	394 (20.7)
					End of follow-up	-	-	640 (33.7)
					Mortality	-	-	867 (45.6)
70–74	**No multimorbidity** (***N***=1853)	4.23 (3.40)	4.98 (3.71)	6.45 (4.72)	**N**	254	414	1185
					Managed care	183 (72.0)	164 (39.6)	124 (10.5)
					End of follow-up	*	*	77 (6.5)
					Mortality	52 (20.5)	227 (54.8)	984 (83.0)
	Low multimorbidity (***N***=779)	-	5.00 (3.48)	6.38 (4.53)	**N**	-	196	583
					Managed care	-	67 (34.2)	76 (13.0)
					End of follow-up	-	54 (27.6)	89 (15.3)
					Mortality	-	75 (38.3)	418 (71.7)
	High multimorbidity (***N***=132)	-	-	6.30 (4.30)	**N**	-	-	132
					Managed care	-	-	*
					End of follow-up	-	-	44 (33.3)
					Mortality	-	-	68 (51.5)
75–79	**No multimorbidity** (***N***=1247)	3.85 (3.15)	4.42 (3.13)	5.27 (3.94)	**N**	118	333	796
					Managed care	79 (66.9)	97 (29.1)	74 (9.3)
					End of follow-up	*	*	*
					Mortality	34 (28.8)	224 (67.3)	712 (89.4)
	Low multimorbidity (***N***=473)	-	4.66 (3.17)	5.76 (4.13)	**N**	-	81	392
					Managed care	-	27 (33.3)	32 (8.2)
					End of follow-up	-	*	*
					Mortality	-	43 (53.1)	344 (87.8)
	High multimorbidity ((***N***=56)	-	-	6.27 (4.27)	**N**	-	-	56
					Managed care	-	-	*
					End of follow-up	-	-	*
					Mortality	-	-	38 (67.9)
80+	**No multimorbidity** (***N***=998)	3.48 (2.58)	3.60 (2.45)	3.95 (2.95)	**N**	111	323	574
					Managed care	50 (45.0)	41 (12.7)	*
					End of follow-up	*	*	*
					Mortality	59 (53.2)	271 (83.9)	550 (95.8)
	Low multimorbidity (***N***=411)	-	4.37 (2.96)	4.94 (3.49)	**N**	-	96	315
					Managed care	-	*	*
					End of follow-up	-	*	*
					Mortality	-	70 (72.9)	289 (91.7)
	High multimorbidity (***N***=40)	-	-	5.18 (3.37)	**N**	-	-	40
					Managed care	-	-	*
					End of follow-up	-	-	*
					Mortality	-	-	34 (85.0)

Abbreviations: *MM* Multimorbidity

1 Cells denoted with a hash mark (-) indicate no observations or data to report

2 Cells denoted with an asterisk (*) indicate redacted data due to cell sizes < 25 observations or individuals

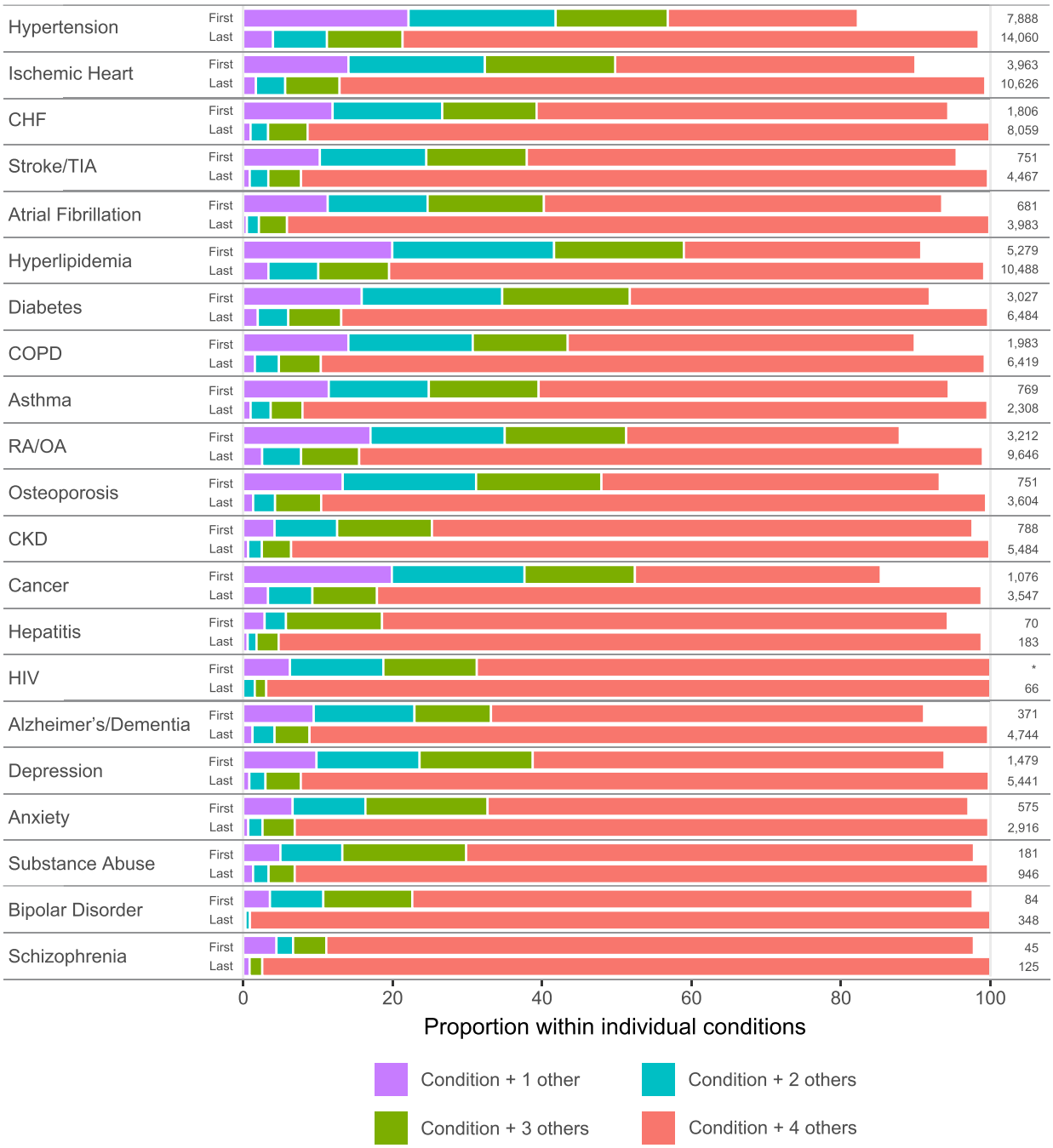
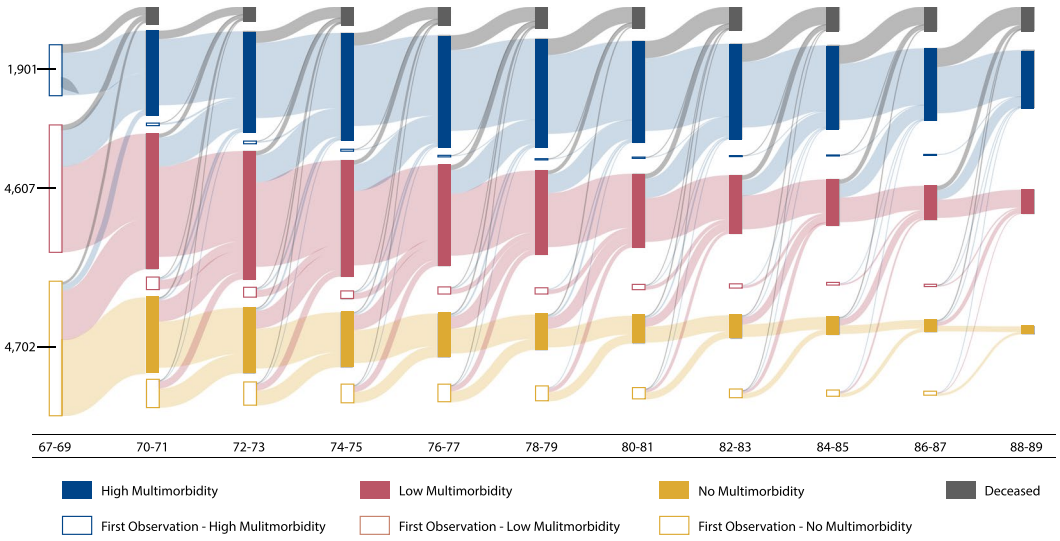


Fig. 1 Distribution of individual chronic diseases among beneficiaries with multimorbidity at first and last observation, 1992–2016 HRS Medicare Beneficiaries

college graduates or those with a post-college education. Female participants acquired additional chronic diseases at a rate of 417.5 per 1,000 py, and males at a slightly lower rate of 415.6 per 1,000 py. Of note, the calculated rates of chronic disease accumulation appear different between racial/ethnic groups, with Hispanic and Black participants having higher levels of multimorbidity than White participants at the outset and slightly lower rates of chronic condition accumulation over the study period, at 416.1 for Hispanic participants, 411.7 for Black participants and 418.1 for White participants.

Table 3 presents health status and utilization outcomes associated with multimorbidity status changes by the end of the study period. Patterns are similar to the first



Total	11,210	11,054	10,661	10,054	9,313	8,417	7,484	6,605	5,572	4,585	3,526
First observation											
High multimorbidity	1,901 (17.0%)	55 (0.5%)	59 (0.6%)	36 (0.4%)	24 (0.3%)	14 (0.2%)	15 (0.2%)	7 (0.1%)	6 (0.1%)	7 (0.2%)	-
Low multimorbidity	4,607 (41.1%)	369 (3.3%)	285 (2.7%)	228 (2.3%)	199 (2.1%)	171 (2.0%)	141 (1.9%)	108 (1.6%)	59 (1.1%)	47 (1.0%)	-
No multimorbidity	4,702 (41.9%)	864 (7.8%)	705 (6.6%)	562 (5.6%)	527 (5.7%)	442 (5.2%)	330 (4.4%)	248 (3.8%)	171 (3.1%)	100 (2.2%)	-
Follow-up observation											
High multimorbidity	-	2,641 (23.9%)	3,143 (29.4%)	3,348 (33.3%)	3,485 (37.4%)	3,392 (40.3%)	3,170 (42.3%)	2,975 (45.0%)	2,608 (46.8%)	2,249 (49.0%)	1,794 (49.6%)
Low multimorbidity	-	4,227 (38.2%)	4,005 (37.5%)	3,634 (36.1%)	3,157 (33.9%)	2,628 (31.2%)	2,299 (30.7%)	1,827 (27.7%)	1,434 (25.7%)	1,064 (23.2%)	741 (20.5%)
No multimorbidity	-	2,382 (21.5%)	2,030 (19.0%)	1,705 (16.9%)	1,360 (14.6%)	1,106 (13.1%)	867 (11.6%)	716 (10.8%)	549 (9.8%)	377 (8.2%)	246 (6.8%)
Deceased	-	516 (4.7%)	434 (4.1%)	541 (5.4%)	561 (6.0%)	664 (7.9%)	662 (8.8%)	724 (11.0%)	745 (13.4%)	741 (16.2%)	745 (21.1%)

Fig. 2 Flow diagram from no multimorbidity to multimorbidity to high multimorbidity and death for 1992–2016 HRS Medicare Beneficiaries

observation, but show large movement into higher multimorbidity levels over time. The high multimorbidity category continued to show higher numbers of hospitalizations and ED visits than the multimorbidity or no multimorbidity category, with the incident high multimorbidity category nearly matching the prevalent category for both. The incident high multimorbidity category surpassed the prevalent category in terms of functional loss, with 32.9% of the incident group having ≥ 4 ADL/IADL limitations versus 24.7% of the prevalent group. Similarly, 15.9% of the group that developed multimorbidity had functional loss by the end of observation versus 5.2% of those who were first observed with multimorbidity. Most striking was the high proportion of cognitive impairment in the multimorbidity categories. Dementia was indicated among 31.5% of the high multimorbidity category but only 15.6% in the multimorbidity category and 9.7% in the no multimorbidity category. Finally, mortality was higher in both incident groups.

Multimorbidity changes across the older age span: transitions to higher burden and death

Figure 2 presents transition to similar or higher multimorbidity levels or death for individuals throughout the observed ages in the study period. Clear bars indicate entry into the study at specific ages, highlighting differences in multimorbidity levels for younger and older beneficiaries – the largest group of individuals entering at high multimorbidity (17.0%) was at the youngest observed ages of 67–69 years, while those entering later were largely characterized by having no multimorbidity (67–70% of individuals age 70 years; this is shown in Fig. 2 under First Observation). Overall, the majority of transitions flowed incrementally to the next multimorbidity category (from no to multimorbidity to high), while transitions to death reflected a slow but steady increase with age (4.7% at first follow-up to 12.1% by last follow-up). The majority of deaths flowed from the high multimorbidity group.

Table 4 presents the average number of years individuals spent in each of the multimorbidity categories as they are followed across the ages they are observed. Not all participants contributed to every category given that some participants never had low or high multimorbidity. Participants aged 67–69 with no multimorbidity at baseline, spent an average of 4.3 years with no multimorbidity, 5.45 years with multimorbidity and 6.36 years with high multimorbidity. From the 'status at last observation columns', 54.9% of those who remain without multimorbidity move out of traditional FFS Medicare coverage and into managed care Medicare coverage; and 58.3% of those who transitioned to high multimorbidity transition to death. Participants who are older at baseline and

started with no multimorbidity spent fewer years in the multimorbidity and high multimorbidity categories: an average of 4.42 and 5.27 years, respectively, for those aged 75–79, and 3.6 and 3.95 years, respectively, for those aged 80 years and older.

Discussion

This study assessed the level of multimorbidity for a national sample of older Medicare fee-for-service beneficiaries in the United States who were followed for 24 years and described the transitions between morbidity levels and the frequency of disease patterns. Different population groups had different multimorbidity burden, including those identified by race, low socioeconomic status, other measures of health status (such as obesity), and education. The categories of no (0–1 disease), multimorbidity (2–4), and high multimorbidity (≥5) help differentiate and highlight differences. The high multimorbidity group had much higher proportions of functional loss, dementia, and rates of healthcare utilization than those with no multimorbidity or moderate levels of multimorbidity. For instance, at baseline, beneficiaries in the high multimorbidity category had up to five times the difference compared with those with moderate multimorbidity, and ten times compared with those with no multimorbidity.

These descriptive values are important to guide more advanced modeling in subsequent analyses. We found substantial heterogeneity in multimorbidity accumulation in late life, with greater multimorbidity burdens evident earlier for different populations, particularly among minoritized groups and those with low socioeconomic status, resulting in differences in baseline levels of chronic disease, accumulation reflecting higher levels of multimorbidity, and death. Non-Hispanic Black adults already demonstrate earlier onset of multimorbidity in middle-age [10], so it is perhaps not surprising that Black Medicare beneficiaries demonstrate higher levels of multimorbidity when they become Medicare age-eligible. Outcomes' values varied by multimorbidity category, notably obesity and lower net worth displayed multimorbidity accumulation early, while low education varied by of chronic disease over time among older adults. Similarly, those who develop multimorbidity of either category later have higher functional loss and mortality despite similar ED visits and hospitalizations than those with earlier onset. These represent different, higher risk conditions that onset at different time periods for older adults.

Similar to others [1], we found high multimorbidity counts (≥5 diseases) provided a meaningful threshold of the burden of multimorbidity on outcomes. The utility and validity of more granular diagnoses depends on the need, but data quality and accuracy are major barriers to their use [27]; our work demonstrates the value of categorization for simple evaluation of multimorbidity among older adults.

More advanced modeling of multimorbidity trajectories requires a deep understanding of trends and fluctuations in the populations as they enter and exit any major data source; this is true in both regular surveys and complex and irregularly captured electronic health record data in fragmented healthcare systems. For instance, we are able to detect lower rates of multimorbidity in earlier birth cohorts by including birth year and age. Working to detect and ameliorate these issues in any source of data is needed to improve the reliability and replicability of analyses.

This study has notable strengths. It leverages population-based data from the HRS complemented by linkage to Medicare claims records. Consequently, these data provide robust socioeconomic information as well as health domains that matter to patients. Linkage to claims permit ascertainment of more granular diagnoses than what are available in health surveys. Further, this work leverages validated algorithms to ascertain diseases that have been previously recommended for the measurement of multimorbidity [22].

A few limitations should be noted. First, we have complete data only on Medicare FFS, not Medicare Advantage, whose populations may be different. Indeed, racial/ethnic minoritized groups are more likely to be enrolled in Medicare Advantage (MA) [28, 29], however there is little evidence of disparities in utilization or performance for beneficiaries between MA and FFS [30]. In addition, per our data use agreement, we were limited to Medicare data files 1992–2016, precluding linkage to the most recent HRS survey waves. There are also competing risks of death and other losses to follow-up, exposing descriptive analysis to both survivorship bias and immortality time bias. In addition, the utilization of healthcare due to access and cost both affects our assessment of chronic diseases and utilization for individuals with fixed or limited financial resources or limited coverage plans. Despite these concerns, this study did observe differences between lower wealth and high multimorbidity levels. Finally, our definition of multimorbidity leveraged a commonly used one, but currently, no consensus exists. The framework was chosen for the chronic diseases that are prevalent, amenable to intervention, and predictive of key outcomes relevant to older adults [31].

This work can inform future research by providing a descriptive profile of ascending multimorbidity burdens and caveats for those evaluating population levels of multimorbidity among older adults from a population health context. Extending the data to middle-aged adults, especially those from historically disadvantaged communities, could detect the onset and development of multimorbidity

for those marginalized groups that develop multimorbidity earlier in the lifespan. Identifying individual high-risk conditions and their synergistic effect on multimorbidity is also needed [32]. Further investigations are needed to assist healthcare delivery models focused on mitigating risk for multimorbidity to achieve reductions in costly unplanned healthcare utilization [5]. Improvements in both our understanding of multimorbidity patterns and sequelae that are most pernicious, as well as devising the best models of care to support participants in managing these conditions, are urgently needed.

Abbreviations

ADL	Activities of Daily Living
BMI	Body mass index
CCW	Chronic conditions warehouse
CIND	Cognitively impaired but not demented
CMS	Centers for Medicare and Medicaid Services
ED	Emergency Department
FFS	Fee-for-service
HRS	Health and Retirement Study
IADL	Instrumental Activities of Daily Living
PY	Person years

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

Supplementary Material 3.

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Authors' contributions
All authors contributed to the conceptualization and revision of this manuscript. DAD, ARQ, SM and MB drafted the manuscript. SM contributed to data curation, data visualization and conducted formal analyses.

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Availability of data and materials
The data that support the findings of this study are available from Centers for Medicaid and Medicare Services (CMS) but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Code used to generate study data are however available from the authors upon reasonable request and data are available upon request with permission from CMS.

Declarations

Ethics approval and consent to participate
Our manuscript involves analysis of secondary data only. As such, the Oregon Health and Science University—Research Integrity Office Institutional Review Board has exempted the need to obtain informed consent and has provided a waiver to use the information in secondary analysis. All methods regarding data were carried out in accordance with relevant guidelines and regulations. The study protocol was approved by Oregon Health and Science University—Research Integrity Office Institutional Review Board (STUDY00017034, STUDY00019414).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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